1.2 Context Document
The research conducted by the Center for Embedded Networked Sensing (CENS) is organized into four technology and five application science areas. The four technology areas are: Programming and Platforms (formerly Systems Research); Multiscale Actuated Sensing; Embeddable Sensors; and Statistics and Data Practice. The application areas are: Terrestrial Ecology Observing Systems; Contaminant Transport; Aquatic; Seismic; and Urban Sensing. The highlights of each area, along with our Knowledge Transfer, Education, and Centerwide outputs summaries follow.

A. Programming and Platforms
CENS systems research strives to advance the state of the art in large-scale observing systems. To this end, our research efforts have focused on two critical areas: the design and evaluation of architectures and programming systems, and the development of practical tools and platforms. Together, these two research directions will enable sophisticated, rapidly reconfigurable, multi-user observing systems that support advanced sensing modalities.

Programming
Taking a sensing system that works in a small scale lab setting out into the real world might seem to be a conceptually simple step. We have repeatedly found that this is not so; the effort to deploy a long-running reliable ENS observing system is currently perhaps an order of magnitude more than that of writing the application itself. Our ongoing research will change this: by developing visibility into a deployed system, by developing languages that simplify application development, and by re-architecting ENS software to ensure the development of manageable software, our research will enable more nimble observing systems.

Our work on layered checkers is an example of programming support needed for application development. Limited insight into deployments, severe resource limitations, and low level systems development are but a few challenges that join together to stymie correct development of wireless and embedded sensing systems. A challenge of particular interest to this research is the management of dynamically created and destroyed resources within these networks. We use a multi-layered approach to reveal incorrect resource usage within sensor network systems. The lowest layer combines traditional data flow and alias analyses to statically track the life of dynamically created and destroyed resources. Upper-layers monitor user-specified invariants in resource usage in order to detect and flag violations. The Lighthouse software is now available for public use.

Another system that can considerably shorten the design-debug-deploy cycle is a network simulator. Avrora simulates a network of motes with high fidelity so that an application developer can test their software on the desktop before deploying it in the real world. Unique to Avrora is the ability to support dynamically updatable code; this mirrors current practice and can help avoid nasty surprises during deployment. Equally unique is the ability to profile application code at arbitrary code locations, a feature that can help identify performance bottlenecks in the system. Avrora has also been integrated with Emstar, and our experiences with Avrora have informed the design of a new object-oriented language, Virgil, tailored for memory-constrained microprocessor systems. During this past year, we have released new versions of Avrora and Virgil, and added support in Avrora for more sensor platforms.

In a multi-pronged approach to improving the reliability of programming sensing applications, we are also investigating a novel programming model for ENS applications called Pleaides. In a significant departure from current practice, Pleaides allows a programmer to program an entire network of sensors as a single entity. Pleaides presents an abstraction of an ENS system as a collection of nodes that can all be tasked together simultaneously within a single program. We have developed a full-fledged prototype of the Pleaides system. In a parallel effort, we have also developed a tool called FSMGen that infers a state machine description of a sensor network program. This tool will help programmers detect subtle errors by visually analyzing a high-level program representation. The tool uses advanced static analysis techniques for this inference.
Finally, our **Tenet** project revisits the architectural foundations of tiered embedded sensing systems. Tenet leverages the fact that every network we deploy has **masters**: 32-bit CPU-class nodes for which power can be engineered. Its architectural principle constrains multi-node fusion functionality to these relatively less constrained nodes. The project has made considerable progress in the past year, having released newer versions of Tenet, revised the task library, added support for new routing protocols like Centroute, and tested a pilot deployment of Cyclops-based motes at the James Reserve.

**Platforms**
A second systems research thrust is the development of mature tools and platforms for deployments of observing systems. Our efforts in this thrust have revolved around two platforms – the LEAP node and the Emstar application development framework– that have transitioned from being research artifacts to being part of a community infrastructure for embedded sensing deployments. Using our seismic and acoustic sensing deployments as drivers, we made significant enhancements to both LEAP and Emstar.

The **LEAP** node takes a fundamentally different approach from the traditional mote-class sensor nodes by emphasizing **energy awareness** for **low average power** instead of **low peak power**, and thus addresses the fundamental inability of the latter to handle complex and high-performance sensing. During the recent year we introduced the LEAP2 hardware, which represents a qualitative advance over the first generation LEAP. It is based on a new low power EMAP2 ASIC that enables direct observation of energy usage of multiple subsystems in real-time at microsecond-scale time resolutions. Using this capability, we have created an **Energy Endoscope** software suite that lets us identify application energy bottlenecks in CPU, storage, and the wireless networking interface, that may only be possible at run time. Future plans entail integrating endoscope measurement feedback with control elements of the OS, such as CPU governors, for adaptive control and adjustment of CPU speed that can lead to energy savings. Applications now being developed with this new platform include seismic sensor networks, structural health monitoring networks, marine sensor systems, and biomedical monitoring. The EMAP functionality has also been incorporated in an MSP430 and TinyOS2 based platform called uLeap.

LEAP and Emstar together form the foundation of GeoNet, a new platform that we have developed for rapidly deployable and distributed geophysical sensing. Developed in collaboration with Reftek, the GeoNet seismic recording system incorporates LEAP with new low-power A/D converters to create a new generation digital acquisition system. It is being field tested in Mexico and Peru networks with software improvements in Disruption Tolerant Shell (DTS), measurement of radio link quality (ETX), improved network logging, a Web interface based on Emstar for deployment and maintenance, network time, and a new routing protocol that caches the routes across sleep cycles for a fast startup. Emstar is also being used as a foundation for VoxNet, our platform for **on-line, interactive** acoustic sensing applications (part of the Wavescope project at MIT). This work integrates multi-hop routing, time synchronization and a new IP-based publish/subscribe mechanism.

**B. Multiscale Actuated Sensing (MAS)**
The Multiscale Actuated Sensing area explores multi-scale and model-driven sensor sampling, iterative and mobile deployment algorithms, and development of the NIMS actuated sensor platform.
Multiscale and Model-Driven Sensor Sampling
Many critical ENS applications such as ecosystem monitoring and stewardship of environments, the efficient distribution of water resources, and characterization of environmental contaminants, call for sensing across a wide range of spatial scales, from centimeters to kilometers. The conventional approach of dense sensor deployment is not feasible due to the impractically large deployment numbers implied; in particular when applied to three-dimensional volumes. Our multiscale sensing algorithms are based on a hierarchical system that enables autonomous arrangement of sensors with the objective of optimizing sensing fidelity, spatial coverage, and mobility characteristics. This system of sensors is designed to achieve efficient high fidelity sampling of dynamic spatiotemporal phenomena.

For example, this multiscale paradigm was recently applied to sampling light intensity. With a target objective of sampling and reconstructing the incident sunlight field, two types of sensors were employed: a camera and Photosynthetic Active Radiation (PAR) point sensors. The camera captured reflected light of a large area; while each discrete sensor measured the incident light at one point. The image data were used in two ways. In a training phase, image data were processed to obtain the ground reflectivity models. Then, ground reflectivity models were applied to segment the field of interest into homogeneous subfields. Within each subfield, the correlation models of the incident light were estimated based on the image data and reflectivity models. Correlation models determined the sampling density in each subfield and enabled a high efficiency sampling of a large, dynamic environment and ultimately reconstruction of this and other phenomena. Actuated sampling of solar radiation has been applied in this program in environments ranging from Southern California to the rainforest in Costa Rica.

Deployment via Iteration and Mobility
The need for efficient monitoring of spatio-temporal dynamics in large environmental applications motivates the use of robotic sensors in order to achieve sufficient spatial coverage. Understanding these dynamics (often not known a priori with high fidelity) requires careful experimental design together with in-field adaptation of the robotic sensing systems. A generally applicable experimental design framework for mobile robot sensing in such environments - Iterative experiment Design for Environmental Applications (IDEA) has been developed to meet this demand. IDEA involves an in-field adaptation of the experiment design: to capture phenomena dynamics (both spatial and temporal) exploiting observations from prior models, iteratively executed experiments and the behavior of the underlying control processes (if known). IDEA framework also provides a systematic method for designing experiments to characterize the interference in the observed environment caused by the robotic sensing system and thus further enhance integrity of returned data. Both analytical and field results have demonstrated how such an approach can optimize the limited campaign time and acquire data that characterizes the spatiotemporal distribution of the observed phenomena with high fidelity. The IDEA framework also incorporates models describing the bounded resources, such as limited energy or limited available time required to obtain measurements. Further, IDEA includes understanding of the spatiotemporal characterization of phenomena distribution to provide larger spatial coverage with careful coordination of actuated sensing operations. Specifically, operation path planning is required in order to maximize information collected, while respecting the resource constraints. This has resulted in the development of an efficient approach, eSIP (efficient Single-robot Informative Path planning), for near-optimally solving the NP-hard optimization problem of planning such informative paths. Results in this program have proven that eSIP provides a guarantee on sampling efficiency under resource constraints. This program has then introduced a general technique, sequential allocation, which can be used to extend any single robot planning algorithm, such as eSIP, for the multi-robot problem. This procedure approximately generalizes any guarantees for the single-robot problem to the multi-robot case. Extensive evaluations of the effectiveness of this approach have been completed on several experiments performed in-field for two important environmental sensing applications.
NIMS Platform Development and Deployments

A new NIMS3D system rapidly deployable cable based robotic system, capable of accurate positioning within its 3-dimensional span, has been developed. In NIMS3D, a node moves via three cables which enable navigation in the 3D volume spanned by the system. Discrete time control algorithms have been implemented to enable precise trajectory tracking, and feedforward control is achieved via an online algorithm for modeling motor behavior. Experimental results show repeatable and accurate positioning and precise tracking of piecewise linear and nonlinear motion profiles. Algorithms have been developed to create energy efficient non linear trajectories that exploit low power regions of the workspace. These have been shown to significantly reduce the energy cost of point to point moves. A second new robotic platform, NIMS-PL; a four cabled planar robot for aquatic sensing applications has also been introduced. Here, our cables are used to maneuver a buoyant end-effector across the surface of a body of water under study. A computationally efficient method of determining optimal tension distributions has been implemented. Further, extensive path planning experiments have been explored with this platform. These use the robot's energy profiling capabilities to create energy efficient paths maximizing sensor utility. NIMS deployments included three terrestrial programs including (1) the analysis of data collected using the NIMS imager at the James Reserve in plant phenology, (2) the collection of images in conjunction with PAR data from the NIMS imager for analysis of sunflecks on bracken ferns, and (3) the installation of a NIMS RD unit perpendicular to the AMARSS transect and the subsequent collection of energy balance data in conjunction with the CENS soils course held at the James Reserve. Water resource monitoring deployments included detailed, multiple transect characterization of the San Joaquin and Merced River confluence and monitoring of urban streams. Physicochemical stream conditions are causing algal impairment at a given site.

C. Embeddable Sensors

During this past year, the sensors research group made several significant advances in sensor development, including Amperometric Nitrate Sensors, Potentiometric Nitrate Sensors, Compact Low-Power Sample-Preparation System, Lab-on-a-Chip, Aquatic Microorganism Analysis System, and Optical Detection of Domoic Acid. In future work, we will emphasize making sensors suitable for rugged field use. Indeed, we have already begun by packaging sensors for field use, and designing and fabricating a common electronic sensor-interface board that can link the packaged sensors with a wireless network. As the sensor group continues to improve and advance its sensor technology, it is also aggressively moving toward system integration for real field use.

Amperometric nitrate sensors

Earlier, we tested the newly designed nitrate sensor chip calibration curve, performed quantification of nitrate sensor selectivity to interfering ions, characterized ionic interference with the sensor, and made the system more reliable. Significant roadblocks to the field deployment of our sensors is the presence of $\text{PO}_4^{3-}$ anions, $\text{Ca}^{2+}$ and $\text{Sr}^{2+}$ cations in sample, which change the measured nitrate concentration by more than 20%, and the response time of the system. An active ionic-filtration method, called Donnan dialysis, is proposed to reduce the impact of interfering cations. To study the factors controlling the speed of the sensing system, a comprehensive theoretical analysis was performed that examines and simulates the physical and electrochemical processes involved. Two prototype Donnan dialysis systems were constructed and tested. The first prototype uses a simple two-compartment system bisected by a selective ion-permeable membrane. While this first system had a good selectivity to cations, the response was very long. The second generation prototype again uses an ion-permeable membrane, but instead of using relatively large stirred reservoirs, the fluid is...
Potentiometric nitrate sensor
The main accomplishments in this project include (1) the successful fabrication and incorporation of nitrate mini-sensors into a sensor system ready for field deployments, (2) laboratory (pre-deployment) testing of the potentiometric nitrate mini-sensors under tap water flow and soil conditions, and (3) successful field-testing of comparable commercial chemical sensors (nitrate and ammonium) in conjunction with physical sensors (soil moisture, temperature, conductivity) in deployments at the dairy farms with sandy and clay soil types. Two field sites with different soil types (sandy and clay soils) located at the dairy farms of Merced County, CA, were selected for test-deployments. Measurements indicate the presence of diel cycles in nitrate/ammonium concentration changes. However, at this stage such change in concentration due to the temperature dependence of the chemical sensor and biological activity (microbial, fungal, plant) cannot be isolated. The sensor temperature dependence issue is currently being addressed in a series of controlled experiments so that we can correct for this effect and better quantify the nitrate response of the sensors.

Sample-preparation system
The system designated to prepare the samples for the electrochemical sensors has progressed far in its development. It consists of an ATMELO Atmega 128L µcontroller, SOS operating system, built-in potentiostat, built-in valve/pump circuitry, and a MICA 2 daughter board for wireless sensor data transmission. The system is nearly completely functional. The software used to manage and control the data flow needs and the stability and noise of the potentiostat circuitry needs to be improved.

Lab-on-Chip aquatic microorganism analysis
This project addresses needs in marine biology research using chip-based technology, which reduces the total sample needed and the detection time. Our project is organized into two main research areas: (1) a chip to monitor the content of the sea water, and (2) a chip that can culture algae under combination of different conditions to screen for factors inducing toxin production. Earlier we built a chip to separate particles based on size. This year, we fabricated an impedance sensor chip that counts particles and made a cell culture chip with integrated combinatorial mixer, which can take in three inputs and generate all the possible combinations of outputs. We will start culturing algae using this chip and expose cells to combinations of different compounds.

Laser-induced fluorescence detection
This system is intended to detect domoic acid (DA), a toxic by product of harmful algal blooms, downstream of the algae culture chip described above. The ultra sensitive optical sensor is based on laser induced fluorescence combined with confocal microscopy and will detect concentrations down to fM in extremely small sample volumes. In this method, molecules of interest are labeled with fluorophores and when each molecule passes through the detection volume a photon burst is observed. The number of peaks per unit time indicates the concentration of domoic acid in the sample. What’s more, any type of molecule tagged with fluorophores can be detected in this manner so this system has broader applicability.
D. Statistics and Data Practices
Last year, research efforts related to data processing, statistical modeling and visualization were sufficient in number to introduce a new area within CENS. By highlighting these functions, we hoped to create opportunities within the center for sharing models and analysis tools across various application and technology-oriented areas. In turn, this group would identify important open statistical questions related to embedded sensing, and propagate a suite of best practices for more mature methodologies. One year into this experiment, we have much to report. This year, we will structure our findings around the lifecycle of a typical sensing deployment: that is, we examine new techniques and supporting platforms related to deployment design, statistical methodologies for and monitoring and administering embedded sensing systems, and research into sharing the resulting data and models.

Deployment design
Based on its extensive experience in the field, CENS has been steadily pursuing the idea of a deployment as an active, reconfigurable system, the result of a steady adaptation or refocusing based on scientific interest or technological advances. In parallel, we have seen the rise of formal modeling efforts within the center and the widespread use of these models to inform all stages of a deployment. This year, we developed adaptive sensor placement strategies that marry these two threads of research, and seek to minimize (once the system is operational) the probability of error when distinguishing between members of a finite collection of competing models. Information criteria are used to select between linear models, with rounds of sampling amplifying our ability to identify the “correct” model. This year we have also added to our already long history in adaptive sampling for robotic systems. In the context of the new NIMS 3D platform, local polynomial regression has been applied to a multi-scale method for learning dynamic light fields. In addition, we have begun exploring a hierarchical Bayesian model for these fields, a model that has, at its core, a polygonal random field for the overall scene.

As deployments became regular occurrences within CENS, members of our Information Studies group initiated a study of the informational needs of scientists and technologists. Despite the fact that our sensing systems are designed with very different scientific goals and involve diverse teams of researchers, a common set of tools can help manage the deployment process. The CENS Deployment Center, for example, allows users to describe their deployment experiences, including lessons learned and troubleshooting techniques, and to provide guidance for future deployments. In so doing, the platform captures the tacit knowledge about equipment setups, sensor sampling and placement strategies, and field preparations that play a critical role in data collection techniques. A parallel goal of this platform is to add value to published CENS data by providing a source of descriptive and contextual information surrounding its collection. In short, through the Deployment Center, we are now able to compile and disseminate deployment best practices within CENS and the entire embedded sensing research community.

Monitoring and Administration
This year, we took a fresh look at the sensor data fusion problem associated with embedded sensing. With the (now classical) localization and detection problems as our primary test cases, we examined the behavior of the marginal utility of including more (static) sensors in a fusion decision. By studying several specific sensor selection algorithms, we found that, as the number of sensors increases, the utility rises sharply at first, but then saturates quickly; the implication being that relatively few sensors should be involved in fusion decisions. Thus, at least for the localization and detection of point sources, large-scale cooperation in data fusion is not needed. In the year ahead, we will extend this work by considering different sensing objectives like coverage, as well as hybrid deployments involving both robotic and static instrumentation. In each case, we will again examine the associated utility function and examine its saturation behavior to assess the degree of cooperation required.
Problems with data quality and integrity are able to derail even the best-designed sensing system. This year, we continued to have a large, cross-institutional effort in anomaly detection and remediation. The UCLA data integrity research group completed its survey of several deployments, both in and out of CENS, and classified, catalogued and defined the most common sensor data faults observed. By separating environmental-, system- and data-specific features of these faults, the group identified the basic theoretical components that should inform fault detection schemes. This group then produced two methodological advances. The first was a kind of voting strategy for identifying non-faulty sensors, or, rather, for targeting outliers and flagging anomalies. In the second, the signature-based fault detection schemes reported last year were extended to include a formal spatio-temporal model for environmental phenomena and is currently being applied to data from the AMARSS transect (see the next topic area for more details). At USC, a kind of meta-analysis was conducted that considered the combination of several anomaly detection schemes, each with different accuracy and robustness characteristics. To be more specific, a hybrid approach was developed that borrowed the best of rule-based methods (leveraging domain expertise), estimation schemes (predicting “normal” system behavior and identifying significant deviations), and statistical learning procedures (classifying directly data into one of several faulty/not-faulty categories).

Acknowledging that sensor failures, communication errors and other anomalies are an inevitable feature of embedded sensing, those who rely on the data from these systems need analysis methodologies that can adapt to missing data. Vigilance is a recent CENS analysis and administration platform that emerged from our extensive experience with multiple-imputation in the context of a model for CO₂ flux based on data from the AMARSS transect. Imputation is based on a functional ANOVA model that provides unique insights into the relationships between the different nodes in the network, their spatial configurations, and their various sensing modalities. While the initial goal of Vigilance was to help researchers assess the impact of sensor failures on the underlying science objectives (as measured through, for example, the overall uncertainty associated with CO₂ flux estimates), the tool also helps both to prioritize sensor replacement strategies, as well as to evaluate potential deployment elaborations. The extensive data analysis exercise that supports Vigilance has set a new standard within CENS and is being used as a basis for further statistical modeling work with the AMARSS transect.

Sharing data and models
Since its inception, CENS has maintained a web-accessible bibliographic database of its publications. This platform, however, did not scale well and did not serve the needs of researchers operating in the shifting terrain of new Web 2.0 technologies. As an alternative, we are transitioning to the eScholarship Repository, a platform maintained by the UC system that allows schools, departments and research centers to deposit their documents with all of the services afforded a state-of-the art repository. This year, we completed the upload of over 1,000 CENS documents, the second largest collection in UCs holdings. This project has involved considerable recoding and “cleaning” of records, including creating rich descriptions of each document (an author list, an abstract, the name of the associated conference or journal, and so on) as well as publisher copyright information. In the year ahead, we will expand our efforts, including the development of semantic links between eScholarship items, and datasets (through SensorBase), deployment plans (through the CENS DC) and other aspects of the larger “data ecology.”

Through this project, we attempt to understand what Internet architectural changes are needed as people share data across millions of sensors attached across the Internet. We hope to enable sharing...
both for sensors operated by traditional scientific research groups, but also, increasingly, by millions of citizen-scientists. This year, we designed and published an architectural description of sensor-Internet sharing and search. We completed work on an efficient indexing and searching mechanisms for time-series sensor data, to help identify portions of a data feed where sudden changes occur. Based on the expectation that data will be shared by many independent organizations, we also developed an extension to SQL that allowed for fast queries over a large number of tables.

This year, we initiated a broad study of cyberinfrastructure projects related to the environmental and atmospheric sciences, including the Long Term Ecological Research Network, CENS, WATERS, CUAHSI and LEAD. Our study focuses less on each specific project than on how the set of them are used by the intersecting domain scientists who deploy them. The outcomes of this work include: (i) The production of fundamental social science about infrastructure development for virtual organizations and for data; (ii) The creation of a functioning virtual organization with a specific set of goals to study data practices and data policies; and (iii) The identification of methods for evaluating cyberinfrastructure efforts. Our long-term goal is to establish a kind of cyberinfrastructure virtual observatory for the study of data, data analysis and visualization. To date, we have developed interview instruments, acquired human subjects review approval, and are now training undergraduates at each research site.

E. Terrestrial ecology
The Terrestrial Ecology Observing Systems area (TEOS) applications research group collaborates with many core CENS groups to design, develop, deploy, evaluate, and support Embedded Networked Sensors (ENS) and instrumented platforms for in situ continuous measurement of environmental, physiological and ecological variables within diverse terrestrial ecosystems. During the fifth year our TEOS members have successfully operated deployed systems of sensors, imagers and platforms, building upon significant functionality for processing, analysis, visualization and web access of data streams. Fixed and mobile arrays, instruments, and associated technologies now deployed and tested at our James Reserve field site are being continually refined as the first wave of CENS systems, toolkits and architectural designs are being shared with our many partner institutions and organizations. Unlike prior years, our focus is now towards looking at ecological processes from a multi-scale and multiple systems approach. Where in the past our projects were essentially free-standing, our faculty and students are now combining systems to providing simultaneous and spatially overlapping measurements. TEOS Research now include 5 project areas Imagers for Animal Observing Systems, Imagers for Plant Observing Systems, Automated Minirhizotron and Arrayed Rhizosphere Sensor Systems (AMARSS+NIMS), Networks and Infrastructure for Environmental Sensing and Image Acquisition, and EcoPDA. Just as importantly, we are now beginning to integrate the first 3 project areas into comprehensive, ecosystems measurement systems.

Imagers for Animal Observing Systems
Camera-based animal observing systems were tested for observing bird behavior and as an aid in herpetological surveys. The key technological needs were to increase the frequency of data capture and to develop image processing software for automated classification of avian behavior activities in real time. In Spring-Summer of 2007, we successfully implemented the Cyclops wireless camera systems. We improved the resolution and increased the number of imaged nestboxes and the frequency of imaging as well as integrated wireless environmental sensors. We also completed an Access database for images and created a user-friendly GUI to move images and environmental data to Sensorbase. We completed one three day experimental pitfall trap deployment in late September, 2007. Accomplishments included the first demonstration of the reliability of Tenet and its integration with our Cyclops hardware and test of a simple but effective background subtraction algorithm on the cyclops node to determine if an image is potentially different from previous images. While this method does produce a number of false positives, it was still able to greatly reduce the number of throwaway (repetitive) images. Finally, we created a simple alarm system to alert the
system user to potential animals trapped in the buckets through e-mail and a continuously updating web page displaying the latest images.

Imagers for Plant Observing Systems
CENS has advanced the field of ground-based environmental imaging with our experience with hardware and analysis from images captured at the James Reserve. This year’s successes include plant imaging, such as with the MossCam, with flower detection, seasonal leaf area measurements, and our general contribution to phenological science. With color thresholding, we have been able to quantify the numbers of blooms of wallflower and timing of blooming of *Ceanothus* using a combination of color thresholding and blob detection. Differing peaks, abundance, and timing may be related to seasonal changes as well as reserves stored in the plants themselves, complicating predictions of species responses to climate change. We explored pseudo-multispectral sensing to track naturally occurring patterns. Using images of a drying moss with both a modified and an unmodified Cyclops camera and illumination from narrow-wavelength LEDs and the state of the moss (wet or dry) was recorded. NDVI analyses showed that wet and dry mosses behave differently than how vegetation observed from satellites behaves. However the signal is strong using the blue channel on the unmodified Cyclops, thus providing us with our first success with multiple-wavelength image sensing.

Networked Minirhizotron and Arrayed Rhizosphere Sensing Systems:
The soil environment is extremely heterogeneous at even a sub-millimeter scale, while soil surface-canopy-atmosphere fluxes integrate over tens of meters to kilometers. We have collected high-resolution spatial and temporal soil data using ten stations along an 80 m transect consisting of an array of belowground sensors including soil CO₂, soil temperature, soil water content, and aboveground air temperature, relative humidity, and photosynthetic active radiation. Our initial analyses have included nonlinear forecasting, path analysis, and wavelet followed by coherence analysis. Nonlinear forecasting shows a chaotic nature of respiration, with both diel and seasonal events. The wavelet patterns show distinct shifts in spectra corresponding to warming and drying periods, and also with monsoonal events. Examination of minirhizotron images show that these events correspond to death and regrowth events of both fungal rhizomorphs and mycorrhizal roots. Surprisingly, the dominant biological factor driving changes in CO₂ concentrations in soil appears to be rhizomorphs, not roots. Soil microbes appear to be critical to actually predicting CO₂, whereas water and temperature drive diffusion rates from soil. We also completed initial testing of NO₃⁻ and NH₄⁺ sensors in the field. We were able to detect a diel signal in both NO₃⁻ and NH₄⁺ similar to that found by the contaminant group. We were also able to detect a monsoonal signal in N mineralization.

Coupling Plant and Soil Dynamics
Along the AMARSS/NIMS transect, the standard bare-surface model was modified to increase the degrees of freedom and allow for a better estimate of sub-surface temperatures. Soil surface temperatures were measured and the model was used to predict the parameter d for separate damping and delay depths of the temperature wave through the soil. Fourier transforms of the complex surface signal allowed applying the model to each component sine wave in order to reconstruct sub-surface temperatures. Results were confirmed with the thermocouple measurements of temperature with depth. The reconstruction from the Fourier transform allowed for heat storage to be calculated as well, resulting in the ability to predict soil surface heat flux along the transect. Values were validated with the buried heat flux plates. From the same site, the soils data showed...
that immediate values of temperature and moisture drive the diffusion of CO$_2$, whereas longer-term (and often delayed) patterns of moisture and temperature drive microbial dynamics, and CO$_2$ concentrations. These complex spatial patterns in heat flux appear to control the spatial complexity in respiration and evaporation. Our new goal is to couple the soil and plant dynamics and create a cylindrical model of CO$_2$ fluxes tied to the drivers of energy, moisture, N and plants and soil microbes.

**EcoPDA: handheld data-logging systems**

All of the basic components for the generic and protocol-specific applications have now been developed and tested, and we are working on integrating them into a complete application and refining the schemas and GUIs. The basic application works as follows: A small SQL database runs on the device and the GUI provides three different ways to interact with it. One is via a table view (like a spreadsheet), one is a form view (like a web form), and one is a spatial view (incorporating simple, interactive diagrams of plots/subplots showing fixed locations and allowing dynamic redrawing based on the data entered). The system is developed for Microsoft Mobile OS, allowing the largest range of suitable hardware. User interviews revealed a range of preferences for types of keyboards and the trade-off between screen size and device bulkiness; the Microsoft platform should allow all users to find a suitable device. TEAM field sites are remote and have limited connectivity (some have internet at a field station, none have internet at the site of sampling), thus data are written to the on-board flash memory and some form of removable media (removable backup).

**F. Contaminant Transport**

The contaminant assessment and management (or “Contam”) research area focuses on developing and implementing ENS technology to support this new observational strategy in the context of mass and energy distributions and fluxes across a range of temporal and synoptic scales. The specific areas of interest for Contam include soils, groundwater, as well as agricultural and urban river systems. The Contam application domain is unique relative to the other three CENS applications in that it is often concerned with enabling adaptive management of environmental problems through engineered responses triggered by ENS observations. Otherwise the Contam research thrusts are interrelated and synergistic both within Contam and through liaisons with other CENS applications and technology areas. In 2007-08, the emphasis in Contam shifted from serial data acquisition and data analysis toward deployments aimed featuring model-driven analysis. In one case, a soil zone moisture, energy, and contaminant propagation models are calibrated and then employed to manage an irrigation system in real time. In another, data assimilation approaches are used to gain the maximum return on deployment investments in the soil irrigation domain, and a major river confluence zone is “digitized” and modeled by using a combination of robotic and human in-the-loop sensing.

**Closed-loop systems**

A major milestone for the CENS soil pylon platform was achieved when researchers successfully demonstrated a closed-loop system for managing not only water applications, but nitrate and salinity levels in Merced test bed soils. CENS research Yeonjeong Park completed her dissertation on this subject in December 2007. Typical results show the soil moisture and salt propagation models autonomously calibrating prior to transitioning to forecast and management modes.
Mass balance
A major highlight of the Contam accomplishments was the **successful execution of a flow and constituent mass balance over a complex major segment** using multiscale ENS in terrestrial-aquatic systems design at the confluence of the San Joaquin and Merced Rivers in Central California. CENS researchers completed over 40 river transects at up- and downstream locations in the area of the confluence which yielded coupled velocity and water quality distributions including temperature, salinity (EC), dissolved oxygen, nitrate, ammonium, pH, and oxidation-reduction potential. Typical cross-sectional distributions were integrated to produce a salinity balance over this zone which is believed to be the first of its kind. A precise account of salinity mixing in confluence zones such as this will eventually enable adaptive management of reservoir releases with respect to salinity distributions in impaired rivers. The results from flow field integrations reveal a viable for rapidly assessing groundwater losses/gains from/to a river over relatively short reaches relative to previous investigations. These groundwater-surface water interactions are currently poorly understood and appear to be important contributors to riparian habitat in many western rivers.

Urban watersheds
The contaminant observations in urban rivers continued to enjoy success along the Malibu watershed. In 2008, **CENS researchers revealed an innovative algal biosensor** which they deployed within the backdrop temperature and light sensors and alongside auto-sampling devices.

Bangladesh arsenic study
Contaminant transport observation **researchers also made their mark internationally**, obtaining unique nutrient cycling observations in sediments beneath a rice paddy in Bangladesh. The study, which is part of an on-going collaboration between CENS and an MIT group led by Professor Charles Harvey, is examining the role that redox conditions play in the release of arsenic species from these sediments.

G. Aquatic
The central theme of the center’s Aquatic application area continues to be the creation and application of a new genre of wireless sensing system that will generate and test novel hypotheses about the processes that control the distribution, growth and demise of aquatic microbial populations. The long-term goal of this research group is to model and predict the dynamics of these populations. A fundamental requirement is to correlate environmental driving forces with microorganismal abundances at spatial and temporal scales relevant to the microorganisms. In turn, this requirement calls for in situ sensing systems that can rapidly respond to and characterize ephemeral or emerging biological events.

Networked Aquatic Microbial Observing Systems
**NAMOS** is the centerpiece for sensor network design and implementation in the aquatic application. A full-scale distributed sensing system was originally deployed in a freshwater ecosystem (Lake Fulmor on the James Reserve). The design constituted a unique ‘hybrid’ system, NAMOS, which comprised a wireless buoy sensing system and a robotic surface vehicle capable of sensing and sampling. This system represented a conscious effort to obtain both high-resolution temporal information on pertinent environmental parameters (provided by the network of static buoys) and high-resolution spatial data from specific locales during periods of interest (using the capabilities of the robotic boat).

Our systems generate contextual information on a variety of physical, chemical and biological features of a water body and intensively observe particular locales during interesting transient events. This is only possible because we use information streaming from the buoys to guide the boat. This distributed system has been deployed multiple times in Lake Fulmor (James Reserve) to study plankton dynamics. The development of NAMOS and its successful use in Lake Fulmor has resulted in a template for the design and construction of sensing systems that can be used in other settings.
Coastal Deployments.
The version of NAMOS developed in fresh water has been expanded during the past 1.5 years into a coastal marine ecosystem (King Harbor of the City of Redondo Beach, California). This coastal embayment suffered microalgal blooms and consequent fish kills in 2005. Algal blooms reoccurred in 2006 without fish kills. We have constructed and deployed a network of stationary sensors nearly continuously in the harbor throughout 2007 that characterize the environmental factors leading to microalgal blooms. City officials have speculated that low oxygen concentration resulting from high algal biomass causes the fish kills. Because microalgal blooms are currently unpredictable, we will monitor data streaming from sensors to identify impending blooms, at which time we will conduct an array of experimental analyses and mobilize the robotic sensor boat.

This work has provided important theoretical insights into both the design and implementation of environmental sensing systems and the environmental factors leading to harmful algal blooms. In addition, the project has practical importance because it will provide government officials in City of Redondo Beach with the information they need to make an informed decision regarding remediation and prevention of future events. A major unanswered question regarding recent increases of HABs and other contamination events in this region is how human activities on land affect the occurrence and severity of these events. Finally, we feel that our collaboration with the City of Redondo Beach is an excellent template for how CENS can assist other coastal municipalities in using distributed sensing systems to address issues surrounding coastal water quality.

A second, and larger-scale implementation of a distributed sensing system in the coastal ocean is underway in conjunction with a NOAA-funded (Monitoring and Event Response for Harmful Algal Blooms) program entitled Rapid Analysis of *Pseudo-nitzschia* & Domoic Acid, Locating Events in near-Real Time. Here, we use CENS hardware, software, and overall approaches in coastal waters near LA Harbor to study the environmental factors leading to toxic algal blooms caused by phytoplankton species that produce the powerful neurotoxin domoic acid. This project brings together CENS- and non-CENS investigators to develop and deploy a network of coastal sensor buoys. The project has just acquired an autonomous submarine (a Webb SLOCUM glider) whose movements and activities will be controlled by information gathered by the static sensor buoys, in a manner similar to the present control of the robotic boat in our NAMOS project. The autonomous robotic boat will also be integrated into the network during the coming year.

H. Seismic applications
The seismology application employs network technology to understand earthquakes and their effects. Our work combines understanding the driving tectonics that generates earthquakes (and volcanoes), the earthquake source itself, how geologic structure traps and focuses waves, and the effects of waves on buildings. Understanding is presently hampered by the paucity of seismic stations in critical areas, both above the earthquake and in the structures themselves, so that measurements are aliased. During this past year we reported scientific findings from our 50 node deployment in Mexico (MASE) and our structural monitoring activities, and made progress on new projects for rapidly deployable networks (Geonet) and geophysical surveying.
**Mexico Seismic Array**

The Mexico seismic network (MASE) became fully operational in April 2006 and ran until April 2007. It comprised 50 seismic stations along a 500 km line across Mexico from Acapulco to Tampico along with 50 autonomous stations installed by colleagues from Caltech. The CENS stations were wirelessly linked to the Internet. The system served as a prototype for continuous environmental monitoring in remote regions by tens to hundreds of stations with data rates of hundreds of samples per second. The CENS network is now in the process of being installed in the Andes in Peru. Stations are connected via 802.11 radios to Raid Array nodes and the data (~2.5 Gbyte) are transmitted via the internet to UCLA every night. The system is controlled by the CENS (designed and built) Data Communications Controller (CCDC), an Intel-Stargate X-scale computer in a mil-spec case with internal radio connected to Yagi or parabolic antennas. Out longest radio link was 50 km, but typically links are 5 to 10 km. Stations act as both data collection nodes and relays. In addition to the seismic stations, about 10 standalone relays were also needed to cover the rugged topography.

This system required development of new software: Duiker interprets the output of a Quanterra digitizer and creates data bundles for radio transmission and local storage. A new Disruption Tolerant Shell (DTS) tracks the passage of data bundles or instructions along the network and handles network breaks without data loss. Network characteristics such as SNR, reliability, and data throughput have been quantified. A paper on the networking (Husker et al., 2008) is in press.

A paper on MASE results presented at the Fall 2007 meeting of the American Geophysical Union won Outstanding Student Paper Award in the tectonophysics section. Of particular interest is the discovery of the subducted slab under Mexico City using P and S wave tomography. Because the slab has no earthquakes that would normally delineate it, its location was previously unknown. Furthermore, scientists have puzzled about why the line of volcanoes strikes east-west and not NW-SE as in the rest of Mexico where they are parallel to the trench. We found not only that where the slab is located but that it is truncated and strikes east-west consistent with the volcanoes. It now appears to have broken off at depth, and this can explain why stresses are too low to cause earthquakes, but the dewatering of the slab nonetheless generates the E-W volcanism.

**Structural Monitoring**

The Factor building continues to provide the most complete test-bed (worldwide) for monitoring state-of-health of buildings. Funding for maintenance and operation has been taken over by the US Geological Survey ANSS (advanced national seismic system) and it has become one of their flagship buildings. Data from Factor is archived at the National IRIS data center where it is a highly requested data set. The Factor ground array records motion of ground at stations located around the building. The total network is composed of 72 within-building seismometers, a borehole station 100 m underneath, and five free-field ground stations on the surface, distributed in a cross. The central station is located at the borehole, the northern one in the Geology basement, east and south stations in the Botanical gardens and a western location in the Life Sciences building. A paper identifying earthquake waves propagating up the building and reflecting from the top has been published along with various conference abstracts and proceedings (Kohler et al., 2007).

Our Structural engineering group has also successfully used Duiker software to control their Quanterras in laboratory structural tests, replacing the much more expensive and cumbersome
commercial package ‘Antelope.’ A joint program between seismic and systems groups has begun to
develop building monitoring networks based on mote-style devices controlled by Tenet software, and
in parallel there is an effort develop a 32-bit-processor-based state of health monitoring SHM box, as
well as new sensors to measure inter-story drift. The goals of the structural and solid earth
seismology groups are sufficiently similar that we have decided to pursue a joint wireless network
development that can serve the dual purposes of free-field (GeoNet) and structural, (SHMnet)
monitoring.

The science objectives of GeoNet and SHMnet are to use a rapidly installable wirelessly linked
seismic network to make near-real time unaliased observations in aftershock or volcanic zones in
RAMP deployments. The immediate technical objective involved collaborating with Reftek to
construct a new generation digital acquisition system (DAS) based on the CENS-developed LEAP
(low-power energy aware processing) system and a newly developed low-power A/D converter from
Texas Instruments (TI) that became available last year. By using the processor in low power mode
for data acquisition, and moderate-power mode for on-site analysis and wireless transmission we
reduce infrastructure for nodes, so that, in theory, hundreds can be deployed rapidly and self
configure. During the first year of GeoNet we have constructed test boxes, performed radio tests on
RF connectivity, and designed a prototype that is under construction with one of the leading
manufacturers of seismic recording systems, Refraction Technology, Dallas Texas, or Reftek. Costs
for the prototype were shared by CENS and NEES (John Wallace’s group) who are interested in
structural health monitoring (SHM). Because of the commonality of needs we now refer to the
development at GeoSHMnet. It involves Wallace, CEE, Estrin, CS, Kaiser, EE, and Davis, ESS. In
preparation for GeoSHMnet we have used the Mexico and Peru networks to field-test software
including improving Disruption Tolerant Shell (DTS), measurement of radio link quality (ETX),
improved network logging, a Web interface based on Emstar for deployment and maintenance,
network time, a new routing protocol that caches the routes across sleep cycles for a fast startup.

HeliAeroMag
Finally, toward the end of this academic year, we started autonomous geophysical surveying using a
remote controlled helicopter (see figure). The USC autonomous helicopter uses differential GPS to
navigate and inertial guidance gyros to track roll pitch and yaw. It can be programmed to fly a flight
grid based on GPS co-ordinates that are sent to the onboard computer. The goal is to generate
galphysical maps of underground, buried magnetic or conductive structures. We purchased a
fluxgate magnetometer and interfaced it to the CENS Data communications controller using CENS
software that was designed for Mexico for data download and rapid data analysis. We conducted a
series of survey experiments in Death Valley using flown magnetometers in an airplane and
magnetometer as part of the ESS 135 Geophysics class in the spring 2007. The preliminary data
revealed that the concept works but we need to reduce noise in the system. A second field trip is
planned to Death Valley as part of the Applied Geophysics Class field trip, April 2008. The package
would be of interest to mineral/oil companies as well as environmental companies.

I. Urban Sensing
The Urban Sensing application area continues to mature, focusing on developing and deploying
“participatory sensing systems” in which new network services, client software, and algorithms
enable everyday mobile phones become a platform for coordinated investigation of the environment
and human activity. Directly related research is burgeoning in this area, for example, in
opportunistic sensing at Dartmouth and participatory urbanism at Intel Research. We have also
found provocative new connections with related work in urban data collection, reality mining,
location sharing services, and continue to participate in the Nokia SensorPlanet initiative. In this
space, CENS work is distinguished by the combination of (1) a participatory focus, which emphasizes
the agency of individuals in deciding what to sense, when, and for whom, (2) the use of model-
assisted sensing, in which widely-available modalities, such as location, are run through models to
generate higher-level inferences, and (3) pilots with domain experts in public health, environmental
science, and community development.
Pilots
Technology research funded by NSF NeTS-FIND, Nokia, Cisco, and others supported such pilots in three identified types of participatory urban sensing:

- **Top-down** data gathering, in which domain experts design experiments or investigations and are the primary recipients of the resulting information. The system’s main role is to coordinate participation in data gathering. Application possibilities include studies of environmental exposure, transportation patterns, and epidemiology. This year’s pilot studies included the DietSense and Harbor Communities Time Location Study pilots, in which autonomously collected images of diet and location, respectively, were used to complement participant self-report in dietary intake and travel behavior studies.

- **Bottom-up** data gathering, in which members of the public advocate or make a case around a topic that they care about, often emerging from a need perceived within a community. Examples include citizen science efforts in the same areas as “top-down” investigation and community asset mapping, such as the Neighborhood Walkability/Bikeability assessment piloted with the Los Angeles non-profit Livable Places, and the ongoing collaboration with UCLA’s Remapping LA project.

- **Self-reflective** data gathering, in which an individual gathers and consumes information from the system in a process of self-discovery. Examples include the exploration of one’s dietary habits, daily driving patterns, overall environmental impacts, and social interactions. The Nokia-supported Personal Environmental Impact Report project is a clear and compelling example of this type of urban sensing. PEIR is a new kind of web-based tool for exploring, reflecting on, and sharing how we impact the environment and how the environment impacts us, using location data gathered autonomously from mobile phones as an index into impact and exposure models.

Especially for the first two types, the concept of a directed sensing “campaign” continues to be an organizing model, though not the only one. In a campaign, willing participants are coordinated by network services to capture data meeting the coverage, credibility, resolution, and diversity requirements of the campaign initiator. Configuration parameters could include institutional affiliations, resource budget and incentives, privacy requirements, the sampling plan, participation types, coverage strategy, and data quality requirements.

In addition to continued work on core platforms for mobile phone based sensing, web-based data storage, and network-attested time-location context, we have discovered and further articulated new research in coordination, verification of human participation, reputation management, model-assisted sensing, incentives, and participatory privacy regulation. In exploring these applications, participatory urban sensing systems’ reliance on cellular, Wi-Fi and internet infrastructure designed for other purposes has challenged us to start designing network services to coordinate participation and provoked the use of models to make inferences about what cannot be directly sensed. And while participatory sensing can “scale down”, bringing value to even a few people, scaling up requires also managing credibility and reputation on behalf of the participants and their self-expressed goals. Once people participate, it is their intimate involvement in the sensing process that must be respected and responsibly designed for, in a secure, flexible, and transparent approach to participation, data control, and privacy regulation.

Several open source software platforms developed at CENS remain central to the urban sensing effort. Campaignr is an XML-configurable tool for manual and automatic capture and upload of location (GPS, cell tower id, WiFi, Bluetooth beacons), sound, image, device and battery information on the Symbian S60 3rd Ed. mobile platform. Used in almost every CENS urban sensing deployment, as well as by our summer interns and collaborating groups at USC and the University of Dublin,
**Campaignr** has proved an invaluable tool for experimentation. At CENS, we have used it on N80 mobile phones provided by Nokia. In considering the 16+hour continuous data collection needs of the Harbor Communities Time Location study, with environmental science faculty Arthur Winer and graduate student Doug Houston, we have pushed the limits of the hardware, discovering and working around Bluetooth and networking stack limitations and unexpected software instabilities; this work continues even now. We are in the process of negotiating industry funding for a port of Campaignr to the Windows Mobile platform that will have additional integration with phone text messaging and voice call support. The **SensorBase** platform has also been used and extended in several urban sensing pilots. A security-enhanced and streamlined version of the codebase was created to meet IRB and data security best practice requirements for the DietSense pilot. Additional user interfaces were developed for the same study to allow quick (and controlled) browsing and deletion of collected samples from their personal store, as well as to select images to be shared with the study investigators. In part by the **PEIR** project, but also because of the more general importance of location traces as primary and contextual data, we have also begun to explore geospatial extensions to SensorBase for location trace data.

**Campaignr and SensorBase** have provided the infrastructure necessary to develop new image processing and activity classification techniques using real data sets. For DietSense, server-side web services were created to discard blurry, underexposed, and overexposed images, as well as to experiment with simple content-based clustering techniques. For the Personal Environmental Impact Report project, a mobility classifier was designed and tested to distinguish between walking and driving activities for input into an automobile pollution emissions model, and then refined by incorporating map-matching techniques. Promising further work was then done to explore the performance of mobility classification using only GSM cell tower and WiFi access point information, without requiring full GPS location trace data.

The CENS External Advisory Board encouraged the group to engage fully with questions of privacy on both a technical and policy level. To gain more experience in identifying and solving privacy requirements under expert oversight, we have participated in two studies requiring human subjects review and approval, DietSense, from the medical IRB, and the Harbor Communities Time Location Study, from the social science IRB. Additionally, we have supported a doctoral student from information studies in investigating CENS urban sensing research and developing with us approaches to privacy issues for urban sensing. This work has resulted in early articulation of participatory privacy regulation, discussed in more detail in the body of the annual report, which as a set of principles complements the further development of technical concepts such as resolution control and selective sharing introduced last year.

Over the next year, we plan to further develop approaches to campaign coordination, reputation and credibility management, and federated authentication that takes into account the varied concepts of identity possible in sensing systems. Additionally, prompted by the PEIR project, we will continue to do further work in activity classification and inferences from models that use widely-available sensing modalities (location, image, sound) as input. Through internal pilot proposals at UCLA and USC, we will also begin to consider other sensor types for use in monitoring personal resource consumption and the urban resource mapping.

**J. Knowledge Transfer & External Partnerships**

The scope of our knowledge transfer and partnership activities has grown with the center. Our initial focus on scholarly dissemination of research related to hardware and software approaches and the development of useable systems in our application test beds has expanded, as our systems and approaches matured, to include a focus on other audiences. Currently, we engage in knowledge transfer and associated partnerships with the broad technology research community in academia and industry as well as domain scientists and other end users. In the past year, in particular, we have focused on creating venues for scientific users to received more detailed, hands-on instruction in the use of ENS systems.

Publications and conference presentations remain key elements of our knowledge transfer strategy with respect to the **technology research community**. In addition to traditional publication
venues, we have now uploaded over 1000 documents to the University of California’s state-of-the-art eScholarship repository. We also provide leaderships in this community by organizing and holding special events, such as our annual research symposium, which this year drew 220 attendees and featured over 80 posters, demonstration and presentations. We collaborate with colleagues and companies that are using our approaches and technologies, such as SOS, Cyclops, ENSboxes, Emstar, and LEAP, in their own research programs and products.

This year again we worked closely with industry partners to exchange knowledge on a variety of topics. Examples include our work with (1) Onset Computers Corp. to interface our motes and their data loggers; (2) Refraction Technologies to incorporate our LEAP II system with their seismometers; (3) National Instruments to develop pathways both to incorporate our technology into their new embedded processing nodes and control software and to include their products into our systems and approaches; (4) Intel to coordinate and support users of the Intel PlatformX platform and to run a year-long undergraduate research program, known as the CENS Intel Scholars Program; and (5) Google to develop image processing tools that work with Picassa, photo organization software.

This year also, we maintained productive partnerships around our urban sensing application with UCLA Center for Research in Engineering, Media and Performance; Cisco Systems; and Nokia, among others.

ENS is a relatively new tool for scientists, and, as such, there is a thirst in scientific communities of various domains for information about how to harness its power to illuminate patterns and processes that would otherwise remain obscured. This year we conducted a summer course on Sensing Technology for the Soil Environment, a three-day hands-on experience with cutting-edge ecological tools and theories. We also conducted a workshop with colleagues in Argentina that identified common science questions and technology needs in the context of Pan-American collaborative environmental observatory research and developed strategies for promoting collaborative research and training in this domain. To support broad adoption and rapid, reliable deployments for researcher at CENS and beyond, we launched the SensorKit program (www.sensorkit.net), which envisions a simple yet powerful distributed sensing system based on commercial hardware and software developed collaboratively by CENS and the USC Information Sciences Institute. The goal is to make ENS systems as simple to set up and use as a standard home WiFi network.

Researchers at CENS also regularly collaborate directly with scientific research groups across the country and world. Noteworthy activity from the past year includes (1) a continued collaboration with the La Selva Biological Field Station in Costa Rica on final development and planning for the deployment of a Rainforest Ecological Portal, a multiuser network of towers, canopy walkways, and distributed sensing nodes in the research areas around the station, (2) utilizing CENS infrastructure at the James Reserve in cooperation with the US Forest Service and Michael Goulden of UC Irvine to construct and operate an 85’ tower with associated instruments to study carbon sequestration, (3) the expansion of sensing infrastructure at a USGS research site on the Merced River, which was established to understand processes controlling the fate and transport of agricultural chemicals in multiple hydrologic compartments, (4) collaboration with the Global Lakes Ecological Observatory Network to identify ways to more effectively observe lake biogeochemical properties and processes.
finding, and (5) initiation, in collaboration with researchers at CalTech and Instituto Geofisico Peru, of a new network of 50 wireless seismometer stations in a transect running across the country of Peru.

Environmental stewardship applications are an increasingly important focus for us in the area of knowledge transfer. Our partnerships with the City of Redondo Beach, for example, continued with the installation of aquatic sensing systems in the local harbor to study the dynamics of algal blooms toward the goal of determining mitigation options for the costly problem. Likewise, we continue to collaborate with the Advanced National Seismic System (USGS) and Incorporated Research Institutions for Seismology to maintain and share data from the world’s most complete test-bed for monitoring the state-of-health of building: The UCLA Factor Building.

This year we were fortunate to have two opportunities to share the center’s accomplishment in technology development and scientific discovery with government officials and members of the public. CENS was an exhibitor at the NSF FY2009 Budget roll out day. Timed to coincide with the budget release and briefing, this event included a public open house at which NSF staff, local students, local professional, and the public learned about CENS through conversation and interactive demonstrations. CENS also exhibited at the University of California Advocacy Day in the state capitol, Sacramento. The purpose was to show case “green” research and highlight the ways that UC contributes to the state. Researchers from UCLA and UCM highlighted the center and projects in our contaminant transport and urban sensing research areas.

K. Education
CENS integrates education, diversity, and research throughout its programs. Through the collaboration of CENS faculty, staff, and students, we have developed infrastructure and programs that support the Center’s education goals: (1) to increase the number and diversity of students pursuing advanced degrees in ENS-related fields and (2) to promote interest and knowledge of ENS technology at all stages of the educational pipeline. CENS education activities support graduate, undergraduate, and pre-college education.

In the past year, CENS continued to utilize the lessons learned in previous years to strengthen and refine our strategies in the areas of graduate, undergraduate, and pre-college education. These efforts have capitalized on the emerging technologies within the Center to create even stronger connections between CENS research and education activities, benefiting the educational community and the Center itself. In the undergraduate research programs, students have made contributions to research in urban sensing, imaging and acoustic sensing, among other areas. We are now expanding these efforts with CENS High School Scholars summer internship program to formalize our work with high school students, which we piloted over the past two years. Our diversity efforts also focused on engaging with partners in the science and engineering community in collaborations designed not only to increase the pool of underrepresented students and women interested in pursuing opportunities within CENS but also supporting diversity efforts within the broader community. Actively building on the successes of our previous years’ work, CENS’ education has made notable accomplishments in all areas of work.

Graduate Student Education
Graduate students are highly involved in CENS through CENS-created curricula, courses, and collaborative research opportunities. Overall, 124 graduate students have participated in CENS research over the past year, including 90 from UCLA, 18 from USC, 8 from UCR, 2 from Caltech, and 4 from UCM. Accomplishments in this area continue to be highlighted by an strong sense of community and multidisciplinary collaboration among graduate students and notable contributions that graduate students have made to the research itself. This collaboration is facilitated by ongoing support activities such as weekly Technical Seminars and Tuesday Teatime networking events, Quarterly Women Ph.D. Lunches, and the annual Research Review and Retreat. Approximately 112 graduate students enrolled in seven graduate courses focused on CENS-related curricula during the 2007-2008 academic year. Graduate students continue to be integral contributors to the Center’s multidisciplinary, inter-institutional research teams. Last year alone, CENS supported conference
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attendance of over 30 graduate students who presented at national and international conferences. CENS is also actively engaged in recruitment activities designed to promote CENS’ graduate programs, particularly for women and underrepresented students. These activities include participation in local and national events and reflect strong partnerships with campus organizations (e.g., SWE, SPUR, CEED, and AGEP), local community colleges (e.g., Santa Monica College) and minority-serving institutions (e.g., CSU Los Angeles, UC Riverside, Loyola Marymount University, and Elizabeth City State University), and all seventeen STCs.

Undergraduate Education
As our education programs continue to evolve, undergraduates are becoming an even more important part of the Center through research opportunities and courses. CENS has established a vital summer internship program that features a several components designed as scaffolding to ensure students’ success in the program. The Tech Camp orientation at the James Reserve is an example of scaffolding that both introduces students to the technology and promotes community-building among students and faculty and graduate student mentors. Last summer, 14 undergraduates participated in the summer research program (10 supported by CENS, 2 supported by REMAP, and 2 supported by UCLA AGEP), of which all were US citizens (or permanent residents), 7 were female, and 5 were underrepresented minorities. Building of the success of our summer program, the CENS Intel Scholars Program, an academic year research program sponsored by Intel supported 12 undergraduate students each year in 2006-2007 and 2007-2008 with a composition of 100% US citizens and 50% female or underrepresented students in both years. This year 57 undergraduates have enrolled in three courses covering ENS topics have been developed and taught by CENS faculty. We continue to benefit from the link between our undergraduate programs and graduate school, now with 14 undergraduate alumni attending CENS-related graduate programs. Our undergraduate research programs are complemented by our diversity efforts, especially the Women@CENS project, which focused on how undergraduate research opportunities promote women’s long-term interest in science and engineering. We are now disseminating the results of our research, which includes a national study with a sample of over 342 undergraduate research programs and the findings from our annual summer internship program evaluations.

Pre-College Activities
CENS pre-college education activities focused on four areas: (1) directly engaging high school students in summer research opportunities, (2) providing training to computer science teachers through the Google CS4ALL Program, (3) development of educational tools and applications that focus on audio/visual ENS technology, and (4) development of a web-based architecture portal through the externally-funded “CENSEI” project which will make our inquiry modules available to teachers and students. CENS obtained funding to expand our summer research program to include high school students, increasing our ability to build the pipeline of students pursuing ENS-related degrees at multiple levels. The CENS High School Scholars Program reflects a partnership with UCLA Graduate School of Education and Information Studies, UCLA Henry Samueli School of Engineering and Applied Science, and the Los Angeles Unified School District. CENS is also part of the CS4ALL program, planned in cooperation with Carnegie Mellon University and University of Washington and funded by a grant from Google. Last summer, we hosted a CS4ALL workshop for middle school and high school teachers with follow-up sessions throughout the year. We are also developing new projects, including collaboration with the Los Angeles Unified School District on the building of a new high school. With regard to data management, we continued our study of data management issues related to CENS to inform development of educational applications with the CENSEI project.
Diversity
Diversity initiatives have been integrated into all CENS education activities, from graduate, to undergraduate, to pre-college and planned professional training activities. To increase the diversity of our graduate and undergraduate student populations, we continue to participate in collaborative activities that support our comprehensive recruitment for graduate and undergraduate students. These activities include CENS sponsored events, participation in four national and two regional conferences; visitation at five local institutions; a national e-mail/advertising campaign to over 7,900 individual faculty, student organization leaders, and department staff; and collaboration with partner organizations, including UCLA CEED, other campus centers, and STCs. CENS also continued to coordinate recruitment activities with other STCs, which includes development of infrastructure and implementation of recruitment activities to draw from a diverse population of students from institutions nationally. In 2008, we received 64 applications from 46 institutions nationally for our undergraduate research program. All of the applicants were US citizen or permanent residents, 39 were women, and 25% were minority students. We also collaborated with the UCLA AGEP program to support undergraduate interns and gave a presentation jointly with other STCs at the national SACNAS conference (NCED, CMOP, CRESIS, SOARS, and LSU).

Future Directions
Our education and diversity programs are an integral part of CENS. As a multi-institutional, multidisciplinary Center, CENS will continue to draw on its strengths (e.g., a growing collaborative research agenda, a community of diverse perspectives, and compelling social implications of the research) to develop education programs that attract and retain high-quality students, particularly US citizens, women, and underrepresented minorities, and increase visibility of ENS technology to broader communities. In the upcoming year, we will focus our efforts on further strengthening our undergraduate research program and multidisciplinary training of CENS graduate students across each CENS institution.

Outputs
The Center remained extremely active through this sixth year of funding. Over the past 12 months, Center faculty, staff, and graduate student contributed to over 100 publications, bringing the total publication count for CENS to over 600. As the result of maturing research priorities, CENS faculty have continued to seek funding outside the STC CORE funds to expand their research. In 2007-2008 alone, CENS administered over $10million in research funds brought into the Center from all sources (exclusive of funds administered by UCLA faculty in their academic departments, or awards made to researchers at partner institutions). Funding has increased every year since inception, and the challenge will be to maintain funding at these levels as large grants made to CENS by the ITR program and ESI program in NSF reach their conclusion. CENS currently has 20 pending proposals under review representing proposals to Industry, Federal Agencies, private foundations, and University grants programs.

CENS management structure remains strong and stable. The Center’s Research Executive Committee (REC) includes representatives from each Center research area and institution, as well as the Administrative, Education, and Program Development Directors. In January 2008, the REC completed the review of the CENS portfolio for the 2008-2009 funding year, identifying 28 research projects across the nine technology and applications areas to receive CORE funding in Year 7.

Media attention continues to raise the profile of CENS within both the University and the academic communities. In the past year, we have drawn media attention to our research in agriculture, aquatic applications, terrestrial applications, and the rapidly growing Urban Sensing area.

Planning is underway for this fall’s 6th Annual Research Review in October 2008 as well as our annual skill building retreat that focuses on uniting technical staff, faculty, and students from all CENS disciplines in exploring a set of defined academic exercises.