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PLANS FOR THE MADISON SQUARE GARDEN 2004 (MSG04) TRACER EXPERIMENT IN MANHATTAN

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1. INTRODUCTION AND BACKGROUND

MSG04 is a study of atmospheric transport and dispersion, to be carried out in the deep urban canyons of Midtown New York City in the area of Madison Square Garden (MSG). Little is known about air flow and hazardous gas dispersion in large cities, since previous urban field experiments have focused on small to medium sized cities with much smaller street canyons. In late Fall 2004, a series of Perfluorocarbon Tracer (PFT) tracers will be released and tracked with about 30 sampling stations at radial distances of about 0.2 and 0.4 km, with vertical profiles near a 250 m tall building (One Penn Plaza). Several anemometers will collect wind data in the MSG vicinity, at street level and roof-top level. MSG04 is expected to provide useful information on flow and dispersion in large urban areas, with a focus on rapid vertical dispersion. The Fall experiment will assist in planning for more extensive studies in future years as part of the Urban Dispersion Program (UDP) supported by the Department of Homeland Security (DHS), and involving collaborations with the Defense Threat Reduction Agency (DTRA), the Department of Energy (DOE), the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA) and other agencies.

The Madison Square Garden July 2004 (MSG04) field experiment will allow continued improvement of our understanding of the atmospheric circulations and rapid vertical dispersion in the deep canyons of very large cities such as New York City. During the past five years, DOE, DHS and DTRA have sponsored field experiments with tracer gas releases in medium-sized cities such as the Urban 2000 experiment in Salt Lake City (Allwine et al., 2002) and the Joint Urban 2003 experiment in Oklahoma City (Allwine et al., 2004), but neither of these cities has an extensive downtown domain with very deep street canyons. The Marine Corps sponsored a related urban tracer experiment in Los Angeles, which has deeper street canyons than SLC or OKC, but not nearly as extensive as NYC. These three urban experiments all report rapid vertical mixing behind buildings, and preliminary wind tunnel and mathematical models of NYC suggest even stronger vertical mixing. For example, a release at street level is expected to mix to the top of the street canyon within about 100 m and within about one minute or less.

In addition to the specific scientific question of rapid vertical mixing, MSG04 and subsequent experiments will address basic urban boundary layer and dispersion issues outlined by Oke (1987), Brown (2000), Hanna and Britter (2002), and other expert reviews. For example, there is concern about how best to account for the heat fluxes at street level and on building sides and roofs in urban areas. Future studies will include high-resolution CFD modeling, such as described by Huber et al. (2000, 2001), who have recently completed a preliminary example of a FLUENT CFD model run in Manhattan street canyons, and have provided recommendations that can be used in MSG04. Over the past two years, Huber has applied the FLUENT model to lower Manhattan to support the environmental impact studies carried out following the 9/11 events at the World Trade Center.

2. DETAILED PLAN FOR THE MADISON SQUARE GARDEN-2004 (MSG04) FIELD EXPERIMENT

The plan for MSG04 makes use of detailed plans developed for two recent urban dispersion experiments, the Urban 2000 study in Salt Lake City (Allwine et al., 2002), and the Joint Urban 2003 (JUT) study in Oklahoma City (Allwine et al., 2004). The overriding science goal is to develop an understanding of flow and dispersion in very large cities such as NYC and several others throughout the world, where very tall buildings extend over an area of diameter 5 to 10 km or more and where the approaching flow is forced to go through the urban area. Previous urban experiments have been in moderate sized cities, such as Salt Lake City and Oklahoma City, where the approaching flow can go around the downtown area. Our estimates of the average building height in the downtown area are about 15 m in Salt Lake City and Oklahoma City, about 30 m in Los Angeles, and about 60 m in New York City. The specific science goals for MSG04 are to:

- Understand flow and dispersion in deep urban canyons within a large urban area.

- Understand rapid vertical transport and dispersion in recirculating eddies adjacent to very tall buildings within a large urban area.

- Carry out tracer experiments with concurrent detailed meteorology to aid in this understanding and in development and evaluation of models.

- Obtain a high quality field data set that can be distributed to others.

The approach to MSG04 is to conduct a six hour tracer experiment as an Intensive Operating Period (IOP) during a three-day window in the fall of 2004 in a 1 km^2 area around Madison Square Garden (MSG). The focus is on deep street canyons and vertical dispersion. The results of MSG04 will be used to plan the more detailed series of experiments in NYC planned as part of UDP.

A tentative plan for the location, duration, and amount of the tracer release, and the placement of concentration samplers and meteorological stations has been devised. These plans were discussed by the 30 participants in a 23-24 February 2004 Workshop, using inputs from participants. The current section describes the plan that was decided by the consensus of the participants. This written material was presented at the Workshop and has been revised into the current format.

The Perfluorocarbon Tracer (PFT) sampling technology has been developed over the past 20-30 years at BNL and has been successfully applied to numerous research studies. Because PFTs have a very low background concentration and can be measured at very low concentrations, low release rates are possible for atmospheric studies. A major advantage of PFTs over other tracers such as SF_6 is that six to eight different PFTs can be released from the same location with different sequences, or from different locations, and all can be detected in the same gas sample. Samplers are available to detect a series of multi-minute samples, and other samplers can be operated in near-real time with fast response. The MSG04 study will use the longer-term averages since those data are most reliable and will optimize the chances of obtaining useful data from the IOP. More details on the PFT sampling system are given in Section 3.

Six PFTs will be released simultaneously during MSG04, at the release locations shown in Figure 1. Four release locations are planned near-ground level outside of Madison Square Garden. The plumes from these four locations are expected to be transported and dispersed slightly differently, and will allow an ensemble of representative plume positions to be determined. The four different release locations around MSG are intended to be upwind, downwind, and on either side of the building, allowing the site-specific effects of local flows to be averaged out. At one of these four sites, two different PFTs will be released in order to confirm the repeatability of the system. The sixth PFT will be released on the north side of the One Penn Plaza building, thus allowing releases on both sides of that building to be investigated, because of the expectation of rapid vertical dispersion around and up the sides of that 250 m building. A 3-d view of the buildings is given in Figure 2, which allows the relative heights of One Penn Plaza, MSG, and other buildings to be seen. The final release locations will depend on the availability of sites and permission from the city authorities.

The PFT release duration was the subject of much discussion at the Workshop. Some persons preferred instantaneous releases. However, because of the need to optimize the useful results, it was decided that, on each day, there will be two two-hour continuous releases, separated by a one hour interval with no release, followed by one hour of sampling with no release. It is hoped that concentrations will decrease significantly during the “no-release” interval so that the two clouds can be distinguished by the samplers. The proposed time of day for the six-hour IOP is 8 am to 2 pm (middle part of day but prior to sea breeze). Two days of experiments are planned in MSG-04 during a three-day window in late fall 2004. Local forecasters will assist in the decision concerning whether to carry out the experiment on a given day. Planned weather conditions are steady periods with no precipitation and no variable cloudiness. Any wind direction can be handled although a S to SW wind is desired. As a preliminary study, to determine the probability of desired wind directions and speeds, there are plans to calculate statistics for winds at the minisodar near MSG, to determine the conditional probability of persistent SW wind, given SW wind observed one or two hours before experiment

By using continuous releases and sampling over two hours, the effects of mesoscale wind variability can be averaged out. For release durations of two hours, the tracer plume will be “flopped” back and forth by the variable mesoscale wind fluctuations, with periods of about 5 to 20 minutes. This happens everywhere but is accentuated in urban areas. Consequently, the tracer plume could go around the left side of a building for 5 minutes and then around the right side of the building for the next ten minutes, and back again, etc. A short-term release with a short averaging time would be subject to these variations; however, a two hour period will average out several of these fluctuations

Possible locations of the 30 PFT samplers were also discussed a great deal at the Workshop. Some persons believed that many of the samplers should be inside the building (MSG, Penn Station, and One Penn Plaza), and others believed that they should be in the Subway. It was decided that the indoors aspect of the problem would be studied in the more extensive future experiments but not in MSG04. However, one PFT sampler was reserved for the main platform inside Penn Station. For the outside samplers, even though we are aiming for SW winds (most common in NYC in fall), we have adopted a conservative approach and plan to locate the samplers around two circles at distances of about 200 m and 400 m from MSG. To ensure capture of tracer gas, there should be sufficient density (2 or 3 every quadrant) so the time-averaged plume does not slip in between around the side of samplers. Given about 30 samplers, assume that there are 12 containers per sampler with 30-minute average per bag. As seen in Figure 1, about 10 samplers are planned near ground level for 360 degrees around MSG in near field (x = 200m). Similarly, about 10 samplers are planned near ground level for 360 degrees at x = 400m. Based on the experiences in Urban 2000 and Joint Urban 2003, samplers should be placed at mid-block (in the street canyon) rather than at intersections.

At each of three locations with ground-level samplers, set up two more samplers to take a "vertical profile" (z = 2 or 3 m, 20 m, 100 m). It was decided that two of these vertical profiles should be on the North and South Sides (windward and leeward) of One Penn Plaza (250 m). The other vertical profile site is yet to be determined, but could be at the Macy's department store.

In addition to the fixed PFT samplers discussed above, about 20 mobile PFT "personal" samplers will be placed on volunteers, as part of the University Partnership between the US EPA National Exposure Research Laboratory (NERL) and the Environmental and Occupational Health Sciences Institute (EOHSI) of the R.W. Johnson Medical School and Rutgers University, Piscataway, New Jersey. Paul Lioy of EOHSI and Jerry Blancato of EPA will coordinate that part of the study and the individuals will wear BNL samplers. About 10 of the personal samplers will involve volunteers completing limited motion tasks at distances ranging from 20 m to 200 m from MSG, and about 10 for of the personal samplers will be used by volunteers to simulate paths traversed by commuters, etc., in MSG/Penn Station. These paths will be repeated or adjusted during the release periods depending upon conditions encountered because of local changes in micrometeorology.

The Workshop participants suggested that a few urban flow and dispersion models be run over the next few months to estimate the flow and dispersion patterns in the MSG04 area and assist in optimum placement of samplers. QUIC-URB has already been run in a preliminary manner, demonstrating the complex flow patterns around MSG, and more runs are planned.

About 10 or 12 meteorological stations will be set up around the area as shown in Figure 1. Assume that the minisodar currently on the EML building (5 km south of MSG) will be relocated to the roof of the Post Office (the low building west of MSG in Figures 1 and 2). Assume that two anemometers will be placed on tall buildings. Assume that about 10 sonic anemometers will be placed near street level and along with the PFT samplers at the three vertical profile sites. Distribute the sonic anemometers within the 1 km^2 domain, but place at mid-block location (in street canyon, not at intersections). Archive the raw data but for analysis purposes, derive averages over 15, 30, and 60 min. The Workshop participants strongly recommended that some meteorological instruments be installed in the MSG area as soon as possible and the data be analyzed prior to the late fall 2004 experiment.

The need for an upwind wind profile site was stressed, to allow the inflow to the city to be determined. The evaluation of urban dispersion models with Urban 2000 data suggested that the use of upwind wind data led to the best predictions of dispersion in the downtown area. However at the moment there is not good upwind data available in NYC (optimum location would be Staten Island or just across the Hudson River in NJ). Several persons suggested that a RASS sounder with 915 MHz wind profiler should be used.

The EPA has been studying flow and dispersion in downtown Manhattan in their wind tunnel. It was suggested that these results could be analyzed and used for planning of the MSG (midtown Manhattan) experiment, since the general geometry of the buildings is similar.

Data QA/QC and archiving were discussed. It was pointed out that a detailed experimental plan should be written soon, including the QA/QC plan. The initial data QA/QC and archiving is the responsibility of BNL, but Dugway Proving Ground will be the final archive (DPG is assuming this role for Joint Urban 2003). The ultimate product will be a modelers data archive consisting of abridged data at optimum averaging times Preliminary analyses will check consistency with general physical relations and baseline models. The primary uses of the MSG04 data are expected to be: demonstration of validity of PFT sampling methodology; examination of contaminanat plume behavior, especially vertical transport phenomena in deep urban canyon settings; development of improved flow and dispersion models and evaluation of urban models (in a very large city with deep street canyons), design of the more extensive future experiments, and guidance for local emergency response agencies.

The expanded and more comprehensive future experiments are currently being discussed in a preliminary manner. Dr. Jerry Allwine is leading a DHS-sponsored consortium that is meeting in the Summer of 2004 to develop detailed plans. It is hoped that the resulting additional experiments will have the following characteristics:

- Extend the sampling domain to 5 km by 5 km

- Conduct at least four experiments in different seasons and possibly in different locations in Manhattan

- Include a meteorological mesonet, with some remote sensors

- Do planning using mesoscale meteorological models, urban dispersion models, and CFD models

- Conduct tracer testing using PFTs and SF_6 to compare results and to provide additional observations for analysis

- Have releases be both continuous and instantaneous, and cover a range of stabilities and wind speeds and directions

- Do at least 10 IOPs during each experiment

- Do some real-time sampling for instantaneous releases

- Include a detailed street canyon experiment (extension of Joint Urban 2003)

- Include at least 10 vertical profiles

- Have over 100 samplers and some remote samplers

- Include subway and inside-building studies

There is a need for a Public Relations (PR) plan, including identification of key persons to communicate with the media. The results of MSG04 and the subsequent experiments and analysis will be improved guidance for NYC emergency response and will be useful to emergency responders in other large cities.

3. THE BNL PFT TRACER SYSTEM

Brookhaven National Laboratory (BNL) has developed analytical techniques and applications for a suite of perfluorocarbon tracers (PFT). PFTs have been extensively used to quantify atmospheric transport and dispersion processes in a variety of meteorological scenarios, ranging in scales from hundreds of miles to urban scales. The extensive PFT results from these experiments were and continue to be used to test and validate models used to predict transport and dispersion in these scenarios.

PFTs can be detected at extremely low levels with parts per quadrillion routinely measured. The technology consists of the tracers themselves, injection techniques, samplers and analyzers. PFTs have the following advantages over conventional tracers:

- Negligible background concentrations of PFTs in the environment. Consequently, only small quantities are needed;

- PFTs are nontoxic, nonreactive, nonflammable, environmentally safe (contains no chlorine), and commercially available;

- PFT technology is the most sensitive of all non-radioactive tracer technologies and concentrations in the range of 10 parts per quadrillion of air (ppq) can be routinely measured;

- The PFTs technology is a multi-tracer technology allowing from six to twelve PFTs to be simultaneously deployed, sampled, and analyzed with the same instrumentation. This results in a lower cost and flexibility in experimental design and data interpretation. All PFTs can be analyzed in 15 minutes on a specially-equipped laboratory-based gas-chromatograph.

PFTs have moderate vapor pressures (some are volatile organic compounds) and as such there are two main methods to deploy (release) them in the atmosphere. They can be dissolved in air and dispersed from a cylinder or they can be released via evaporative/diffusive methods. PFTs can be sampled using conventional sampling techniques for whole air samples such as bags, bottles and syringes. BNL has over 800 one-liter Tedlar bags that can be utilized if required. These bags can be filled using portable, battery-operated pumps. They can be filled rapidly, for point in time sampling, or slowly at a controlled rate for integrated sampling. PFTs, like most hydrocarbons can be adsorbed on to carbonaceous material. Unlike most hydrocarbons, the PFTs are fairly stable with temperature (in the absence of a reducing catalyst), which allows them to be easily thermally desorbed from the adsorbent for analysis. Thus, PFTs are more typically sampled onto adsorbents and later desorbed for analysis. BNL has two tracer sampling systems that utilize adsorbents. The first, the Brookhaven Atmospheric Tracer Sampler (BATS), is an autosampler that is pre-programmed to pull a known amount of air through any one of 23 sampling tubes (each containing a carbonaceous adsorbent) at a specified time and rate. The BATS is a key to accurate tracer sample acquisition as it has timing, triggering, recording and pumping modules. Each BATS unit is independent and battery operated allowing for wide sampler placement with unattended operation (if required).

The second sorbent-type sampler is the Capillary Adsorbent Tube Sampler (CATS) which is a small cigarette sized glass tube containing a carbonaceous adsorbent specific for the PFTs. This sampler can be used dynamically (flowing a sample through the CATS similar to the BATS sampling) or passively (opening only one end to allow the CATS to sample by diffusion).

The passive mode allows a time integrated PFT concentration to be measured in a simple manner. The dynamic mode allows larger volumes of air to be sampled (for very low PFT concentrations). BNL has two 125-meter tubes that are outfitted with CATS every 5 meters. The CATS can then be deployed vertically along the face of a building and sampled dynamically by pumping on the main tube. Both BATS and CATS are shipped back to the laboratory for PFT analysis.

In addition, several portable real-time PFT analyzers are available. One detects four different PFTs per five minutes sample down to the ambient background of the PFTs in air. Another real time instrument can analyze PFTs down to a part per trillion but cannot separate the various PFTs. Portable analyzers are used to determine timing of events (e.g., arrival of the plume) which in turn allows on-the-fly changes in the sampling protocol to best capture the event. The portable analyzer can also be used to follow the concentration history of a particle point over the duration of the event and at very small timing intervals.

The initial PFT releases will focus on rapid vertical mixing in the Urban Canyon in the area surrounding MSG. BATS, CATS, bags and the portable analyzer will be used to sample the PFTs. Both 125-meter sample lines will be deployed along with two to four tubing bundles that will be deployed vertically at two or three locations on the faces of buildings to obtain vertical concentration profiles. The sample lines will be used to obtain vertical concentration profiles via an integrated sample taken over the life of the event. The PFT release procedure will consist of six PFTS species being released continuously for a period of two hours, with a one-hour interval, followed by another continuous release for two hours. The tube bundles will sample at heights of about 2 m, 20 to 30 m, and at the building top and each tube will be connected to a BATS unit. BATS units will be programmed to sample 1/10 to 1/20 event lifetime intervals. Ground level sampling will be accomplished using the remaining BATS units, CATS and bag samples. BATS units will capture integrated samples for the entire event. Each of the 23 CATS in the BATS lid will capture a specific interval and no specific interval will be missed. Students will help in the sample collection process, primarily to take bag samples for point in time samples and to take integrated samples on CATS using small handheld, battery-operated pumps. It is envisioned that 250 to 500+ samples will be taken/analyzed. Laboratory turnaround will be one to three weeks (~50 analyses per day).

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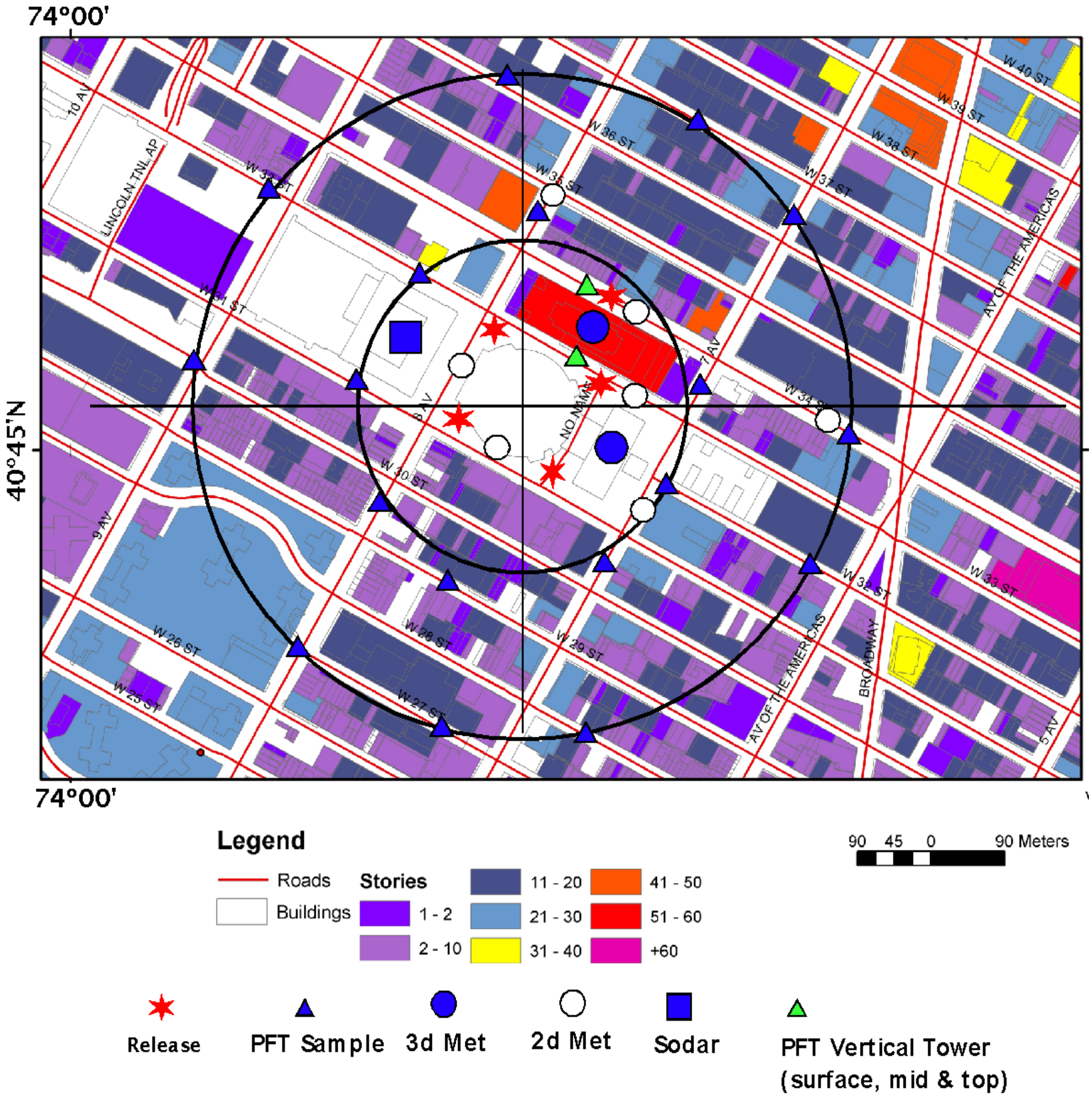

Figure 1 – Map of Madison Square Garden area showing tentative locations for PFT tracer releases (red stars) for MSG04 field experiment. PFT tracer sampling locations near street level are shown as blue triangles. Locations with PFT vertical soundings on building faces are shown as green triangles. The minisodar location is shown as a blue square. Rooftop meteorological stations are shown as blue circles. Street canyon sonic anemometer locations are shown as open circles.

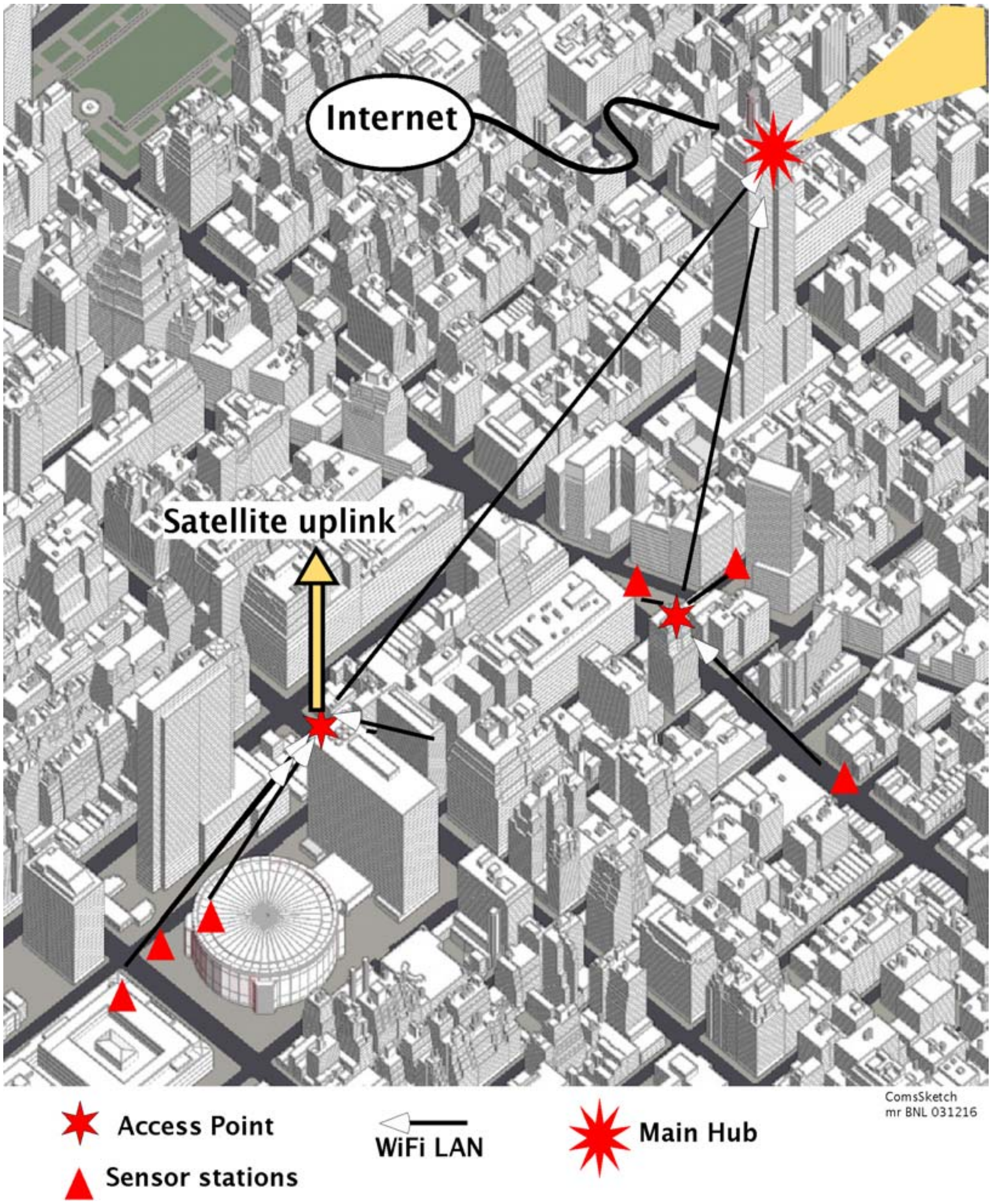

Figure 2 – Three-dimensional view of the buildings around MSG, which is the circular building in the near left. It is 700 m from MSG to the Empire State Building, where the Internet star is located. The W-E line runs approximately from MSG to the “Internet” oval. One Penn Plaza is the 250 m tall building located just north of MSG.