Summary of the Population-Environment Research Network Cyberseminar
What are the Remote Sensing Data Needs of the Population-Environment Research Community?

10-24 May 2010

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Introduction

The Population-Environment Research Network (PERN) was launched in 2001 by the International Union for the Scientific Study of Population (IUSSP) and is co-sponsored by the International Human Dimensions Programme on Global Environmental Change (IHDP). PERN's mission is to facilitate scientific analysis and dialogue about population-environment (PE) relationships. PERN is an Internet-based network that is open and free to all who are interested in population environment research, and it currently has 1,700 members representing almost all countries and many disciplines.

In May 2010 PERN conducted a two-week cyberseminar, co-sponsored by the Group on Earth Observations (GEO) and the NASA Socioeconomic Data and Applications Center (SEDAC)[1], on the remote sensing data needs of this important research community. There were nine invited experts, approximately 570 researchers participated, and the seminar had 55 postings over a two-week period. The discussion was structured around the following set of questions.

1. What are the branches of population-environment research that use remote sensing data?
2. Which sensors/instruments are most often used in PE research?
3. What are the barriers to greater use?
4. How do indicators constructed from remotely sensed data compare with those collected through field research or in surveys?
5. What data integration issues are faced in combining data from different sources and resolutions?
6. What are the prerequisites for inter- and transdisciplinary research in terms of standards of data interpretation, access to data from different sources, and the social and political purposes for which the data are used?
7. What are the societal benefits from the fundamental or applied research (using remote sensing data) engaged in by the PE research community?
8. Are there common data needs that can be articulated by our community?
9. What are the major programmed missions such as NASA's Decadal Missions (from the US National Research Council's Decadal Survey) or those of the European Space Agency, China, Brazil, India, or commercial providers, that may meet important data gaps?
10. Recognizing that past research may have been constrained by the capabilities of existing sensors, what capabilities might be desired by this community for future missions (which hopefully are also technically feasible to build and launch)?
11. Is there a way to build a broad consensus across the social science community for the remote sensing data that is most needed by this community? What kind of process would be required?

[1] SEDAC has also provided in-kind support for PERN since its inception.

What follows is a summary of the contributions structured around these questions. The expert statements can be found at http://www.populationenvironmentresearch.org/seminars.jsp, and a full archive of all the statements and discussions can be found at **http://listserver.ciesin.columbia.edu/cgi-bin/wa?A1=ind1005&L=PERNSEMINARS**.

Summary of Discussion by Question

1. **What are the branches of population-environment research that use remote sensing data?**

Population-environment researchers have a long history of using remote sensing (RS) in their research. One of the best funded branches of population-environment research has focused on land use and land cover change (LULCC), particularly in tropical forest regions. This line of research has evolved from early efforts to link deforestation to demographic and social processes at rather coarse scales to an examination of more complex, multi-level processes at different scales, from household to national. Two major publications, *People and Pixels* (Liverman et al. 1998) and *People and the Environment* (Fox *et al.* 2003), have explored the data, methods, and results of LUCC research, and meta-analyses have synthesized major findings from RS-derived research on deforestation (Rudel 2005, Geist & Lambin 2002) and agricultural intensification (Keys & McConnell 2005). More recently population-environment researchers have developed new uses of remote sensing data. A search of the PERN eLibrary on the term "remote sensing" turns up 70 publications that, in addition to LULCC, include research on urban growth, urban heat islands, human health, human impacts on coastal areas and wetlands, hazards risk, desertification and land degradation, and population modeling.

Sean Sloan, an invited expert and a geographer at the University of Melbourne in Australia, mentioned the confluence of two strands of LULCC research, one focused on large areas (so called "global environmental change" research or GEC), and one on micro-studies of deforestation (he termed "human ecology" or HE). He wrote, "One of the more exciting developments in recent PE research has been the gradual fusion of the GEC and HE branches with respect to the analysis of tropical reforestation. This merged branch, which I term here 'GEC-HE', observes transitions from tropical deforestation to reforestation at a national scale and over long periods, as per the GEC branch, but does so with sufficient richness of social data as to empirically model the human dimension of the transition in detail, as per the HE branch. "

There were quite a number of urban environmental applications that were described by the invited experts, such as efforts to understand spatial variation in poverty and wellbeing. According to the expert statement of Maik Netzband, a geographer at Ruhr University in Germany:

> Recent research activities have focused on the identification of the poor in the context of slums, informal settlements, marginal areas and low income neighborhoods, as well as their spatial embeddedness in a number of fast growing cities and megacities across the globe (Netzband et al., 2009). The spatial profile that traces poverty in complex, cluttered, uncontrolled, and fast growing urbanized regions is elaborated by means of very high resolution (VHR) remote sensing data and the associated geospatial techniques. There are several issues in addressing the question of how remote sensing can help access the spatial configuration of urban informal settlements and living conditions. These include: (1) Examining whether a spatial correlation exists

> between the results of the different thematic land-use/ land-cover analyses; (2) Identifying land-use patterns combined with a vegetation index analysis (NDVI) and Urban Structure Types (UST); and (3) Estimating spatial indicators for quality of life and vulnerability to natural hazards such as flooding.

Each of these methods is described in greater detail in his statement.

One of the earliest applications of imagery (e.g. Landsat MSS) was for population counts, and several participants weighed in on this. Atiqur Rahman, an invited expert, PERN steering committee member and a geographer at Jamia Millia Islamia University in New Delhi, India, described such applications in urban areas:

> Although the number of people living in an areas cannot be seen directly on the remotely sensed data, it can used as an indirect tool for population estimation by using different methods. The number of dwelling units can be multiplied by the average size of the household in obtaining the estimation of population from remote sensing data (aerial photographs and high resolution satellite data) using three different methods: i) dwelling unit technique, ii) built-up areas technique, and iii) housing density technique (Taragi et. al., 1999). Another method, the land use area density method (multiplying urban built up areas by average population densities) was used in estimating the population of Bhimawaram town in India using IRS LISS-I data of 1988 (Raghavaswami, 1994).

Anne Puissant, an invited expert from University of Strasbourg in France, added some additional methods, including the pixel based approach, in which "the population is directly linked (and estimated) to the information contained in one pixel," and the homogenous areas approach, in which mean population density is estimated for areas of similar housing density. However, the latter has some limitations:

> The major challenge remains the automatic extraction of homogeneous areas (urban blocks) from available imagery at different spatial and spectral resolutions. A proposed solution is to use simultaneously the available satellite image from medium to high spatial resolution to extract automatically urban blocks. The proposed method detailed in Kurtz et al. (in press 2010) is based on a region based approach: the spatial context of the urban objects and the semantic relationships of these last ones between the available resolutions are used to enhance the simultaneous analysis of both medium spatial resolution and high spatial resolution. First results are encouraging but further research should be continued in this domain.

A demographer, Jack Baker, said he has used remote sensing for estimating populations in New Mexico and a forested area of Paraguay. In the latter case, he was able to extract information on age/sex structure, but not much of use for population counts. The US Bureau of the Census is using imagery to reallocate populations from coarser or out-dated population counts in Haiti and Pakistan. The Haiti estimates are on a 100m pixel size, which is much higher resolution than global data sets such as Gridded Population of the World, GRUMP, or Landscan. However, it was generally acknowledged that there are limitations for using imagery to estimate population in sparsely settled areas. It can also be difficult in regions where buildings are made of the same materials as surrounding landscapes.

Health applications were also mentioned by a few participants. Sarah Henderson, an epidemiologist at University of British Columbia, uses active fire products, aerosol optical depth (AOD) and true color images to assess the air quality impacts of forest fire smoke, and to estimate populations exposed.

William Pan, a professor of international health at Johns Hopkins School of Public Health, mentioned that "RS applications and data provide enormous potential for surveillance and early warning detection of infectious disease. Examples have been developed for malaria, cholera and meningitis, with a lot of research required to further improve these systems. Most vector-borne and zoonotic infections that occur in both urban and rural areas of developing or developed countries could likely benefit from further lines of research toward linking RS, population and health outcomes." Pan added that RS data are being used in disaster relief situations and that they could be used to monitor water resources, which will be an increasingly important PE issue.

2. Which sensors/instruments are most often used in PE research?

So called "moderate resolution" (15-30m resolution) imagery such as Landsat, ASTER, IRS, and CBERS data have been the workhorses of PE research. It was pointed out that time series data are very important for change analysis, and that only Landsat is able to cover close to 40 years continually (with the exception of recent gaps). Coarser resolution data (e.g. MODIS) are valuable because of their daily repeat coverage, especially over cloud covered areas. There was also discussion on the utility of night-time lights imagery (DMSP-OLS) for urban area mapping, even though the spatial resolution is on the order of 1-3km.

Stephen Walsh, an invited expert based at University of North Carolina, is using some not-so-common sensors and innovative approaches to data fusion. According to Walsh, in a study of the Galapagos Islands off the coast of Ecuador:

> We are fusing MODIS with a Landsat/ASTER data set through down-scaling approaches to study phenological cycles and inter-annual shifts in LULC and changes in land productivity, as well as ecological metrics to describe the spatial organization of LULC and productivity patterns through time, particularly, land fragmentation as a "push" factor to out-migration. In the Galapagos, where farms are relatively small and land parcels are irregular in shape and size, we are fusing Hyperion hyper-spectral data, Advanced Land Imager multi-spectral data, and QuickBird hyper-spatial data to assess LULC composition and structure. We use a linear and non-linear mixture modeling approach to define LULC fractions on a pixel-by-pixel basis (Adams et al. 1995) for the 30-meter cells of Hyperion and ALI (Walsh et al. 2008a, c). Classified QuickBird imagery is used to define spectral endmembers through Object-Based Image Analysis (OBIA) techniques (Blaschke et al. 2001). Different image objects are represented at multiple scales simultaneously via a hierarchical network of homogenous image regions that contain information about the texture, shape, and spectral response patterns. ALOS PALSAR, Synthetic Aperture Radar data, is also being integrated to describe image texture and structural information to improve our discrimination of similar LULC types and age/density indicators of invasive species.

The goal, according to Walsh, "is to link people to the land that they influence, directly and indirectly, and to map and model LULC change trajectories and the social-ecological drivers of change."

Also, a number of researchers are using high resolution satellite imagery (<=1 meter). Rahman provided an overview of the utility of such imagery for urban analysis:

> "High resolution satellite imagery including IKONOS 1 meter/pixel, Quick Bird 0.61 meter/pixel, and IRS-1D 5.8 meter/pixel pan and multispectral data have used to detect, identify, and delineate individual house type. They can be used to separate formal and informal settlement structures, to identify new slum developments, to map the condition of the slum environment (with *in situ* data), to map greenbelts, and to understand urban encroachment (Sur et. al., 2004). Also vacant lands, urban housing, urban utilities and infrastructure, solid waste management, urban transportation and traffic planning, urban hydrology, urban cadastral and real estate, urban ecological hazards, and urban census data all can be mapped, monitored, and analyzed using remote sensing data sets."

Bill McConnell, a geographer at Michigan State University, described research near the Wolong Panda Reserve in China that uses QuickBird images for "ground truthing". His team has gone to the field with a printed version to work with farmers to identify land cover types that appear on the imagery. They can then go back in time using the extensive Landsat archive (which is now completely open and free of charge), and also combine these data with MODIS, which gives the regular repeat cycles. He suggested that the QuickBird imagery provides a "missing link" in the information array. Hien Pham of the Laboratory for Spatial Analysis and Regional Economy in Quebec described research in which they used QuickBird images (60cm of resolution) to extract trees and grass by an object-oriented classification. They then combined the vegetation information with cadastral and socioeconomic data. The imagery shows variations in tree and grass cover at the census district level (600 people in average), which will help them to see how the amount of trees in yards varies across neighborhoods and if there is a link with socioeconomic status and quality of life. Rahman described the utility of WorldView-2 data – an instrument with 8 spectral bands and between .46 and 2m resolution – for urban slum mapping, stating, "WV-2 is quite useful for the identification of housing type, assessing slums and squatter settlements, delineation of open drains (an important factors for assessing the quality of life of the people living in the low class residential areas)."

Walsh echoed McConnell's comment on the utility of high resolution imagery for ground truthing. He stated, "We routinely use Quickbird, Ikonos, and airphotos as a 'ground control' tools in the field, combined with GPS units, base stations that we erect where necessary, video cameras, and more as we strategically collect ground control data. Customizing the aerial photography and satellite data is essential, e.g., including GIS overlays of roads, rivers, cultural features, and more as needed, particularly if one is going to engage local people in a description of current, or even more importantly, historical land use patterns to calibrate or validate an image time series of what once was." He cautioned, however, that this resolution data is difficult for land cover mapping, especially in urban areas, owing to shadows being confused with water and other spectrally dark surfaces. They have developed some workarounds that he describes further in his posting.

Regarding Hyperion, a hyperspectral instrument with more than 200 spectral bands, and to data fusion more generally, Kelley Crews, an invited expert, SEDAC user working group member, and geographer at the University of Texas, wrote:

> Note that many such multi-sensor approaches mean scaling both spectrally and spatially, and the combination needs to be carefully handled to not muddy the data quality. But these data sources can help to build an analog for unmixing in the rest of the image, and thus assist in extracting greater information than possible

without the use of such a bridge. While much of this work has been in vegetation studies, I think there are some very compelling avenues of social science research (including population estimation) where these data would be useful.

Walsh commented, "Regarding Hyperion data, AVIRIS, and other hyper-spectral data, a challenge often is to reduce the dimensionality of the data cube for various applications. Depending upon study area and seasonality, water vapor and other environmental constituents degrade spectral channels, and other things impinge on various spectral regions as well." Again, they have developed some workarounds.

Terry Slonecker, a geographer at the US Geological Survey, put in a plug for thermal bands and radar imagery:

> Kelley's points about multi-sensors approaches are both valid and appropriate and especially important when dealing with small-footprint sensors that can only be used for sampling approaches…. [E]specially for population studies, thermal infrared and radar sensors provide distinct advantages for population studies, especially when used in combination (fusion) with better resolution optical sensors. Thermal bands, such as on Landsat, are often discarded but provide very valuable information about the thermal crossover, especially in desert environments, and radar sensors react to structure and provide valuable separability of human-constructions, even when they are made of indigenous materials and not spectrally separable.

3. What are the barriers to greater use?

Meshach Ojile, a geographer at Niger Delta University in Nigeria, voiced concerns over the costs of hardware, software, and imagery, especially for developing country universities. He also mentioned the need for capacity building. Several suggestions were made concerning sources of free software (e.g. the American Museum of Natural History has a site dedicated to free-ware remote sensing packages)[2] and imagery (e.g., Landsat, MODIS, CBERS, and IRS data), but it was acknowledged that lack of training, low bandwidth, and hardware costs could still be barriers. The AMNH web site also has free training materials and tutorials, but these may not substitute for hands-on training. Despite the resources mentioned, Pan argued:

> This may just be perceived inaccessibility by others, but whenever I collaborate with colleagues from developing countries, there is an underlying belief that certain sensors and data are just not available to them (for several reasons). Future, and perhaps current, sensors need to be promoted more broadly with access and data clearly described.

Crews added that issues of reliable electricity, internet connectivity, and language-dependent literacy are very important in the developing world, "a reminder that even our most sophisticated and critical social science or remote sensing needs in many ways come down to an issue of development."

[2] American Museum of Natural History's Remote Sensing Resources page can be found at http://biodiversityinformatics.amnh.org/index.php?section_id=6. A whole list of free image processing packages can be found at http://biodiversityinformatics.amnh.org/index.php?section=rsr_links_image.

According to Baker, from a demography/anthropology perspective:

> One barrier to using RS for a person like me is a perception of an inability of techniques like interpolation to adequately capture more fine-grained population distributions. So among demographers who use GIS and are also intensively trained and highly-experienced (like me) in demographic modeling there is some skepticism. In fact, interpolations tell us nothing at all about smaller-scale population dynamics. This breeds a healthy skepticism if your goal is to model and understand population dynamics at small-area levels necessary for really getting at PE issues.

Yet, he mentioned that, especially in the developing world, demographers never have the kind of data for small areas that they would like to have in order to model population dynamics, so there seems to be a slow realization among demographers that RS data can be used effectively to fill in these gaps. He added that RS-derived land cover can be used to predict some demographic characteristics (such as age/sex distribution, ethnicity) which are important for population modeling, and also for PE research.

In response to the discussions on population estimation, Parameswara Krishnan, a demographer at the University of Botswana, countered, "Unless data on distinct individual units are available, no worthwhile explanatory research is possible… In demographic studies, there are populations who cannot be reached (e.g. tribals) as they live in inaccessible areas. The RS technique is useful to get at their total number. But no data on individuals is possible to obtain. Unless data on individuals are gleaned, no explanatory analysis is possible. For this we require face to face interview."

Apart from disciplinary and economic barriers to access, Sloan mentioned some technical issues in his statement:

> for time-series analysis of tropical forest-cover change, only Landsat MSS or AVHRR imagery are available to define baseline conditions in the 1980s. Neither is well suited to the task, however. Landsat MSS imagery has a *relatively* fine spatial resolution (80 m pixels). But archived MSS images of tropical areas during the 1980s are so few, so infrequent and often so cloudy that that their utility to estimate forest-cover change over 1980-1990 for even for a small country is virtually nil. Indeed, Nezry et al. (1993) estimate that, in a given year in Sumatra, the probability of acquiring a single Landsat MSS, Landsat TM or a SPOT satellite image having <70% cloud cover (which is still *very* cloudy) is only 0.25.

Ethical issues may also represent barriers for research. Questions on the ethics of using high resolution imagery were raised by Dave Kendall at the University of Melbourne:

> Satellite images, aerial photos, and Google Street View comprise a relatively small part of my research investigating the relationship between social factors such as people's preferences and socioeconomics, and the diversity and distribution of urban vegetation in south-eastern Australia. While I have obtained consent to investigate peoples' gardens, I have been surprised how much information is available remotely, especially through high resolution aerial photos and Google Street View. What views do people have on the ethics of using remote sensing in social research?

Slonecker mentioned he had published a paper on this topic (Slonecker et al. 1998), and raised some related issues. "For example, in your research, you discovered illegal drugs crops, even in small urban gardens. What would your ethical and legal responsibility be? Would your personal and professional ethics conflict with legal expectations? And this may vary widely in different countries."

Moderator de Sherbinin mentioned that the SEDAC project has a web page devoted to Confidentiality Issues in Geospatial Data Applications, including a PNAS article from 2005 on "Confidentiality and spatially explicit data: Concerns and challenge" written by a number of PERN members.[3] Chris Small, a remote sensing scientist at Columbia University, mentioned a paper on the policy implications of high resolution commercial remote sensing of interest, in which they make a pretty convincing argument that the pros outweigh the cons in terms of privacy.[4]

4. How do indicators constructed from remotely sensed data compare with those collected through field research or in surveys?

In his statement, Sloan describes the difficulty of obtaining data on land *use* (i.e., how people are using the land) from data on land *cover* (i.e., vegetation cover):

> The distinctions between land-cover classifications derived from RS data versus field surveys are many. Apart from the obvious scale advantages of RS data (geographic and temporal), the distinctions usually reduce to what a field survey can measure but RS data cannot. In PE research, the principal distinction is the degree to which the land-cover classification reflects land use/intervention, as opposed to mere land cover. For example, while a field survey may distinguish unmanaged natural forest fallows from those managed to produce food and fibre by observing differences in tree species composition, to the satellite image, which 'sees' only the biophysical properties of the fallow (e.g., leafy vigour, shadow, texture), all such fallows may appear identical. Thus, the scale advantages and convenience of RS observations are offset by an inferior ability to discern subtle biophysical properties having implications for land use and human-environment interactions.

Malanding Jaiteh and Alex de Sherbinin at CIESIN sought to develop some indicators of environmental change, which de Sherbinin shared with participants. They used MODIS data processed by South Dakota State University to measure deforestation and GIMMS/AVHRR data processed by FAO and ISRIC to measure land degradation, both at the country level. There are substantial difficulties in carrying out such work and methodological obstacles to be overcome, but with its wall-to-wall coverage, the potential for remote sensing data to contribute to indicators of environmental change on a global scale is irrefutable. The satellite estimates of deforestation are not directly comparable to the country-collected data reported in the FAO Forest Resources Assessment (FRA) for a number of reasons (outlined in their contribution), but it was discouraging to find that the satellite derived deforestation estimates had almost correlation with the FRA data on forest cover change. Similarly, colleagues at FAO commented that the satellite derived land degradation estimates could not be corroborated through field research in a few countries.

Henderson contributed this based on her work on air pollution and human health:

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[3] See http://sedac.ciesin.columbia.edu/confidentiality/
[4] See http://www.policyarchive.org/handle/10207/6465

> There is a lot of work to show that, for example, MODIS AOD agrees well with surface measurements of ambient particulate matter in the southeastern US, but poorly in the northwestern US. In areas where surface monitoring is limited or unavailable we really don't know how well RS-based metrics are performing, but we assume that they are better than no metric at all. In recent work I was able to show that epidemiologic results from a MODIS-based exposure metric agreed very well with those based on air quality measurements. At this stage several of us are leaning towards fused metrics, taking advantages of the strengths of RS (spatially expansive, uncertain) and the strengths of field measurements (spatially limited, certain).

5. **What data integration issues are faced in combining data from different sources and resolutions?**

This question is largely addressed in the summary to question #2 above. Readers are especially encouraged to read the posts by Walsh and Crews for more details on data integration challenges.

6. **What are the prerequisites for inter- and transdisciplinary research in terms of standards of data interpretation, access to data from different sources, and the social and political purposes for which the data are used?**

Paul Sutton, a geographer at the University of Denver, made the point that certain data (such as those from night-time lights) may not be the *best* way to measure something of interest (e.g. urban extent or patterns of CO2 emissions), but they can serve as a useful *independent* measurement that helps to reduce uncertainty and error.

Henderson found that mistakes she had made in image processing were only uncovered by reviewers, so she advised social scientists to work closely with remote sensing scientists in order to avoid costly errors. She added:

> At this stage I still don't feel comfortable about pursuing any project without (1) consulting a remote sensing scientist or, preferably, (2) having a remote sensing scientist as a collaborator. While the research might look new and exciting to the public health community, it doesn't mean much if the data have been stretched beyond their limitations.

7. **What are the societal benefits from the fundamental or applied research (using remote sensing data) engaged in by the PE research community?**

Moderator de Sherbinin asked the provocative question, "After 15-20 years of PE research using remote sensing, what are the major insights that we've gained, and have they informed policy? How has knowing how Amazonian households at different lifecycle stages make use of parcels benefited society at large? How does knowing about forest transitions help us transition to sustainability – and is the understanding of forest transitions in one region even relevant in other regions? And, if the results are not always generalizable or policy relevant, are there methodological innovations that have been developed or barriers that have been broken that have enabled beneficial applications in other areas?"

Regarding Amazonian research, Pan took up the challenge, offering this response:

> I view this from a public health and environmental perspective. There are clear linkages between forest and disease transitions of a region that are strongly related to demographic and economic forces influencing these relationships. I think that the science of understanding how people alter their environment in relation to demographic, economic and, to some extent, environmental cycles is progressing nicely to provide potentially policy recommendations to minimize environmental degradation and maximize human well-being. However, I do think there is a big disconnect between this type of research with public health that can further quantify measures of human well-being. I think that the disconnect is not caused by a lack of motivation of the sciences to collaborate, rather, the few opportunities available to conduct research that is truly multi-disciplinary that merges expertise and methods from multiple fields. These types of studies are not small (i.e., larger than National Institutes of Health R01 type mechanisms) and require huge commitments by donors and governments to support their assimilation.

In his statement, Sloan argued that many of the societal benefits of PE research, including the LULCC branch, have not been fully realized:

> The potential societal benefits of GEC-HE research using remote sensing are immense, albeit largely unrealized. In my view, the principal benefit is that, for the first time, policy makers may draw upon a *rich, national-scale* empirical basis to develop social/agricultural/economic policy relevant to large-scale environmental issues, namely those concerning tropical forests. Here, by 'empirical basis' I refer to national, spatially-explicit statistical models integrating observations of socio-economic and environmental change.

Jason Bremner, a geographer at the Population Reference Bureau, echoed Sloan's sense that the research had not been widely used by policy makers:

> While I think RS has led to major insights related to human dimensions of environmental change (particularly land use), I don't think these insights have entered into the policy or public discourse. I believe there are two reasons for this: (1) The insights remain largely confined to peer-reviewed journals and the academic community. Conservation and development practitioners and policymakers don't have access to and don't read the peer-reviewed journals, and the academic community doesn't have an incentive to communicate in forms other than peer-reviewed research. (2)The insights involve increasingly technical RS and survey methods that are largely unknown and understood by those outside of this community. So our insights are less understood by decision makers and the public than ever. Finding new ways to communicate what we know to those with no technical knowledge of the field is the great challenge. Doing this in developing countries and in different languages adds additional challenges.

Sloan did mention that the research on LULCC has provided a methodological basis for monitoring deforestation, as required for Reducing Emissions from Deforestation and Forest Degradation (REDD) under a post-Kyoto agreement on carbon emissions for the UN Framework Convention on Climate Change.

Invited expert Paul Sutton, together with colleagues Benjamin Tuttle of the University of Denver and Chris Elvidge of NOAA's National Geophysical Data Center, make the case that the night-time lights image of the world can serve, like the Keeling Curve does for CO_2 emissions, as a signal that the human-environment system is unbalanced. This could then provide an entry point for policy makers to investigate how the system needs fixing (which inevitably demands more remote sensing data to perform the diagnosis):

> Fortunately, there is an abundant amount of information in the form of remotely sensed satellite imagery that can inform our understanding of the human-environment-sustainability problematic. In contrast to the globally aggregate measure that the CO_2 data at Mauna Loa provides, remotely sensed nocturnal images of the Earth provide spatially explicit data that can be used as inputs for a suite of methods and analyses that enable more accurate measurement, mapping, and monitoring of human impacts on the Earth.

Sandra Baptista, a geographer and post-doc at CIESIN, responded to the expert contributions on RS-derived research on urban inequalities with some thoughts on how to make it more policy relevant:

> I suggest that we strive to go well beyond mapping the spatial heterogeneity of urban poverty (e.g., informal settlements, low income neighborhoods, marginal areas) by developing RS research activities that can help us better understand the multiscale and multidimensional patterns and processes of social inequality in urban and metropolitan settings including socio-spatial heterogeneities related to mobility, quality of life, and hazard vulnerability. In other words, I think that the search for equity, in cities of varying locations, forms and sizes, requires that the PE research community develop our understanding of cities, city-regions, and urban networks as human habitats in which not only vulnerable, but also resilient social groups live, work, circulate, and adapt.

Rahman responded, “In Indian cities the government departments are removing these colonies and in Delhi alone almost every month one such big colony is removed which houses over 1,000 households. So the RS studies now is being oriented towards the rehabilitation of these poorer people and in that process satellite data e.g. IKONOS and Quick bird is being used … to find the suitable locations so that they can be properly rehabilitated and in some cases they get better residences compared to earlier ones.”

Baptista also had thoughts on how this research could become more relevant to multilevel governance, land-use regulation, and participatory planning:

> The issue of simplicity (i.e., enabling people to use satellite-derived products accurately, reliably, and easily) and awareness of emerging opportunities to utilize social media and novel data streams are two critical points raised by Kelley Crews. I would like to see high resolution RS data and web-accessible derived products become more accessible to diverse local stakeholders/decision-makers who are interested in monitoring local social and environmental change, including educators and students in secondary and post-secondary schools.

8. Are there common data needs that can be articulated by our community?

Crews had some useful observations here that are quoted verbatim. She pleads for continuity, pointability, visibility, and simplicity:

> By **continuity** I mean that new sensor systems are [readily] compatible with historical remote sensing archives. Social science questions rarely can be answered only on the basis of the last six months' data (real-time hazard assessment notwithstanding – more on that shortly). I would rather sacrifice choosing a spectral band to be placed exactly where I needed it than give up the ability to compare to Landsat archives from 1972 on (this applies to hyperspectral systems too, though would take upscaling work).
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> Back to the concern regarding real-time response (different from prediction), especially to hazards and disasters such as volcanic eruption, hurricane, tsunami, flooding, earthquake, armed attack, or space shuttle crashes. Some countries/regions have developed or are in the process of developing their own [usually lower altitude and geosynschronous] micro-satellite sensor systems for monitoring and rapid response. But a global answer negates geosynchronous observations of the entire planet at any reasonable spatial scale; yet the return time for many sensor systems can be inadequate depending where in the orbital path that platform is when the disaster occurs. Cost likely prohibits a network of satellites for this purpose (though that is one alternative), but a **pointable** system (such as SPOT) would in effect reduce return time without adding the same level of cost as a second sensor system (presumably—here I focus on social science needs and leave the feasibility studies and implementation to the engineers).
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> My third item, **visibility**, seems apparent. Social scientists are increasingly moving to object-based classification rather than pixel-based, or else relying upon interpretation of pattern (automated or otherwise) since many social phenomena are not necessarily spectrally distinct. For affordable high spatial resolution data we often use a panchromatic band that tends to be four times higher resolution than the multispectral bands onboard. While panchromatic imagery can appear quite "sharp" in densely built areas, it actually can appear relatively "muddy" in others because of the panchromatic band's placement. In many sensor systems, the panchromatic band covers portions of the visible (red) and infrared (near) spectra, effectively obscuring one of the traditionally most easily separable [landscape] areas of the spectrum. Granted, this design was likely needed to attain strong enough readings at-sensor with that smaller pixel size, but the effect is troublesome in rural and heterogeneously vegetated areas.
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> The fourth and final item, **simplicity**, increases in importance with increasing speed as remote sensing applications become more social and more interdisciplinary. People without any formal training in remote sensing design or application expect to be able to use satellite-derived products accurately, reliably, and easily. The "fix" to this issue is more operations-based than design-based, and NASA (and USGS) has greatly facilitated the ease of use by extracting and posting web-accessible derived products that are geometrically corrected (to some degree) and by offering commonly requested data over large regions (e.g., MODIS fire data). An upgrade might involve processing regions of interest rather than using scene-based boundaries. And these agencies would still need input from users about the types of products that they would like to be able to avail themselves of "off the shelf". Recall that these products need not be derived from passive sensor systems only (consider most RADAR-derived topographic and interferometric products, such as digital elevation models or DEMs). Imagine having a standard high-spatial and –vertical resolution LIDAR-based DEM for flooding vulnerability, or a quickly produced non-bare earth DEM (i.e.,

including buildings) that could be quickly compared after an earthquake to the base product for rapid and synoptic estimation of damage and targeting of intervention.

The plea for continuity was repeated by PERN co-coordinator Susana Adamo in her posting. According to Adamo, "In developing countries, data about environmental characteristics and dynamics at different points in time are not always readily available, and still this information is crucial for recreating and understanding changing contexts over time. In this sense, the use of remotely sensed data and analysis techniques can provide a partial solution to the lack of information for the study of population-environment interactions, complementing ground data collection, offering different scales of spatial coverage, and enabling (to some extent) retrospectives studies (Jensen 2000; Rindfuss and Stern 1998)."

Sutton argued against more 1m or pointable sensors, saying that 1m data are very difficult to deal with from a computational perspective. His recommended characteristics are: (1) Nocturnal observation (spectral, spatial, and temporal resolution of Nightsat – see question 10 below); (2) Roughly Landsat spatial resolution (30-100 m pixels); (3) Global Coverage; (4) Time series at roughly an annual temporal resolution.

9. What are the major programmed missions such as NASA's Decadal Missions (from the US National Research Council's Decadal Survey) or those of the European Space Agency, China, Brazil, India, or commercial providers, that may meet important data gaps?

Crews addressed this question by outlining the new capabilities the PE research community will have with a number of sensors. Should funding permit, there will be new/improved capabilities in understanding drought, soil health, and food security (HyspIRI); forest structural succession (DESDynI); areas of ozone pollution or scarcity (at different levels in the atmosphere of course, with the latter related to cataracts and skin cancer) (GEO-CAPE and GPSRO); and potential high-risk areas of vector-borne and zoonotic diseases (HyspIRI, DESDnyI, and SWOT, the first two for terrestrial systems and the third for aquatic).[4]

Beyond this contribution, there were no inputs on other planned NASA missions[5], ESA missions, or future missions by national space agencies in Chiana, Brazil or India.

[4] DESDnyI = Deformation, Ecosystem Structure, and Dynamics of Ice; HyspIRI = Hyperspectral Infrared Imager; GEO-CAPE = Geostationary Coastal and Air Pollution Events; GPSRO = Operational GPS Radio Occultation; and SWOT = Surface Water and Ocean Topography (NAS, 2007).

[5] A longer list of NASA decadal survey missions and their capabilities is available in an extract from a presentation by Stephen Volz, Associate Director for Flight Programs at NASA, at http://www.populationenvironmentresearch.org/papers/Volz_EOMandDecadalSurvey_extract.pdf.

10. **Recognizing that past research may have been constrained by the capabilities of existing sensors, what capabilities might be desired by this community for future missions (which hopefully are also technically feasible to build and launch)?**

This question overlaps some with question #8, so responses to that question are also relevant. Still, moderator de Sherbinin made the following plea for contributions to address this question:

> I realize that social scientists have been takers rather than market makers (to use the market place metaphor) as far as remote sensing imagery goes. I think social scientists have proven very adept at making use of an increasing variety of imagery, often in ways never imagined by the scientists and engineers who designed the sensors. Now, we have a chance to have a place at the table – through NASA and GEO – to suggest what kinds of imagery might be useful for social science research and the nine societal benefit areas. Let's see if any ideas emerge.

Sutton argued for the need for a NightSat mission, which would provide approximately 50m resolution night-time lights imagery for much finer-scale analysis (than DMSP-OLS) of the patterns of urban built-up areas, among other things. Further information on this proposed sensor can be found in Elvidge et al. (2008).[6] Pan added, "There is an obvious need for improving sensors in urban environments that has already been mentioned, and I am in strong support of those recommendations."

11. **Is there a way to build a broad consensus across the social science community for the remote sensing data that is most needed by this community? What kind of process would be required?**

This question was not taken up by most of the participants, though Lisa Johnson, a geographer at Florida State University, did make the following observation:

> I think this is an interesting question, when the panel is entirely geographers! I think RS is not really a part of the broad social science community... Part of building consensus is to first make RS relevant to social scientists, which also means making GIS relevant to social scientists. Some inroads are being made in this regard. I now teach GIS to economists, political scientists, sociologists, demographers, and public health students with much greater frequency. I have to say though, despite my efforts, many of them think remote sensing amounts to the pretty background underlying the other data they're concerned with, such as roads, geocoded points, etc.

[Moderator's note: The panelists were not chosen on the basis of disciplinary affiliation, but when it came down to finding PE researchers who also had high levels of expertise in remote sensing image analysis and familiarity with the wide range of sensors available, there were few outside the field of geography with the necessary qualifications. SEDAC will be approaching the American Association of Geographers to develop a mechanism for bringing social science requirements to the attention of NASA engineers.]

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[6] Also posted by Sutton to the cyberseminar discussion list.

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