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U.S. EPA perspective on integrating Earth System Science with Land Surface Research

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This is one of three responses formally provided by the EPA to the National Research Council in response to the Request For Information concerning the 2017-2027 NRC Decadal Survey in Earth Science and Applications from Space.

This paper addresses United States Environmental Protection Agency (EPA) operational and research challenges for the next decade in the utilization of space-based observations for the assessment of terrestrial properties affecting land, water, and air resources, and human health. Effectively assessing and mitigating exposures requires techniques for rapid measurement of a stressor on diverse geographic, temporal, and biologic scales and an enhanced infrastructure for rapid deployment of resources to address imminent threats. In concert with EPA's mission to protect human health and the environment, satellite remote sensing offers a tool to identify and quantify relevant exposures that may pose a threat to ecosystems and/or human health. National efforts to reduce environmental risk require the best available scientific information, optimally linking *in situ* measurements with space-based remotely sensed data to investigate exposures at various spatial and temporal scales.

EPA has relied heavily on a variety of National Aeronautics and Space Administration (NASA) missions to assess land cover change on both spatial and temporal dimensions. For example:

- MODIS Terra and Aqua normalized difference vegetation index (NDVI) time-series data has been used to track land cover change in the Great Lakes Region, Puerto Rico and the US Virgin Islands, and the Albemarle-Pamlico Basin in order to identify drivers of lake and river eutrophication and coral reef degradation. This time-series research identified cropping practice changes within the Great Lakes region which corresponded to changes in legislation allowing increases in biofuel production for the year 2007 (Shao et. al, 2010).

- EPA is investigating the full characterization of atmospheric deposition exposure from NO_X, SO_X, and O_3 in order to address total deposition budgets of these pollutants. Improved gaseous and particulate flux estimates affecting these pollutants are critically needed to reduce uncertainty in setting and implementing effective secondary ambient standards. Leaf area, assessed both *in situ* and remotely from space-based sensors (MODIS and Landsat), is a critical input in modeling aerosol flux within forest canopies. These are a few examples of recent research and regional applications using space-borne observations to address key issues affecting both water and air quality.

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The following questions were generated from specific projects and tasks embedded within the 2016-2021 research plan within the Office of Research and Development and from US EPA Regional remote sensing applications. This subset of research and application areas is intended to give a sense of the scope and domain of EPA concerns which require a combination of *in situ* and space-borne remotely sensed data.

- Which mechanisms (i.e., land use changes, best management practices, and proximal anthropogenic stressors) negatively affect or improve watershed condition?
- What linkages can be made between riparian buffer quality and water quality attributes (i.e., base flow, sediment, nutrients, temperature, and dissolved oxygen)?
- How is pesticide drift affected by the proximity of agricultural fields, landscape and meteorological features?
- What geospatial characteristics of upland stressors contribute to the formation of harmful algal blooms and contribute to coral reef degradation?
- How is surface water nutrient enrichment linked to mountaintop mining, the construction of valley fills, or the extraction of oil and gas resources?
- How have climate change, draining (direct and through groundwater abstraction), and development altered the fabric of the landscape in decreasing both the abundance of depressional wetlands and the timing, depth, and duration of inundation?
- How does watershed integrity, resilience, and recovery potential in landscapes with high densities of "geographically isolated" wetlands affect geomorphology, water quality, and biological integrity?
- Can watershed resiliency and recovery potential be compared over spatial and temporal scales using land cover, hydrodynamic and human demographic change analyses?
- How does size, spatial patterning, and wetting/drying cycles of depressional wetlands affect their presence and function as resilient nodes on the landscape?
- Can *in situ* and remotely sensed data quantify wetland landscape connectivity?

- Are there associations between measured air and lake temperature across a range of lake morphologies?

- Can multispectral imagery identify sources of high nutrient loading into streams and rivers from agricultural fields?

- Can space-borne observational systems detect mine tailings in historic mining sites along the Sierra Nevada region (California and Nevada)?

- Can airborne and ground hyperspectral imaging combined with *in situ* sampling provide a cost effective approach in the identification of trace metals released from the Carson River Mercury Site in western Nevada?

- Can space-borne/airborne observational systems assist in the assessment of dam integrity and tailing pile stability at high priority sites nationwide?

- Can high-resolution imagery combined with seasonal data acquisitions provide information on abandoned tanks within the Yakima tribal lands in western Washington?

Answering these questions requires a continuity of the imagery types and data products produced by the current NASA and European Space Agency (ESA) missions (Landsat 8, Sentinal-2a and Sentinal-3 (ESA), MODIS Terra and Aqua, GRACE, EO-1, VIIRS). These requirements will partially be met with the launch of the planned missions (GRACE-FO, GEDI, HyspIRI, ICESat-2, LIST, NI-SAR). The greatest challenges in addressing these EPA centric issues are having access to remotely sensed data types that are (1) at the appropriate resolution: spatial, temporal, radiometric, and spectral, (2) not cost prohibitive, and (3) accessible and easily digestible to end users in common file formats and databases.

The continuity and data suite provided by the MODIS sensor has driven many applications in environmental research. We have successfully classified land cover using temporal profiles at a 250 x 250 m resolution in a number of differing climatic regions within the United States and its Territories. The Visible Infrared Imaging Radiometer Suite (VIIRS) was launched in 2011 with the intent to extend measurements initiated by MODIS. However, spatial resolution has decreased from 250 m to 375 m, thereby compromising the identification of land cover types that previously were resolved at the finer resolution of the MODIS sensor. Also, the number of data products previously produced by the NASA Science Team, are no longer available with this new mission. Leaf area index (LAI) is one product casualty missing in the VIIRS suite of data products. This omission will prevent this input from replacing static LAI values currently utilized by regional and continental air and climate models. The Hyperion sensor aboard the EO-1 platform has provided value added data useful for answering many of the questions addressed above, especially in the identification of mine tailings and other trace metals located in arid environments. The planned hyperspectral missions, both Germany's Enmap followed by NASA's HyspIRI, will allow for better coverage of areas of interest and timely data acquisition. The US EPA has also used LIDAR and RADAR data operationally and for research to identify areas of mining and to quantify forest structure and above-ground carbon.

The Landsat program has provided a rich legacy of data over the past 30-plus years for terrestrial remote sensing. The Multi-Resolution Land Characteristics Consortium (MRLC) has utilized this data to derive the National Land Cover Dataset (NLCD) and all the associated data products, a collection of data that has driven land use/land cover change modeling, a critical component of the US EPA EnviroAtlas (http://enviroatlas.epa.gov/enviroatlas/). Having two Landsat satellites in orbit simultaneously would reduce revisit time in half, increasing the probability of cloud free data capture.

In contrast to the above medium-to-coarse spatial resolution data types, many EPA applications require high spatial resolution imagery to characterize and monitor both environmental condition (e.g., trees, streams, riparian and road vegetation buffers) and anthropogenic nutrient and contaminate sources (e.g., impervious surfaces, industrial infrastructure, pipes). Imagery requirements for resolving objects within the built environment include sub-meter to five meter pixel size multi-spectral, multi-temporal visible-infrared and shortwave infrared (SWIR) imagery. High resolution LiDAR and photogrammetric-derived point clouds and derivatives are also needed to accurately represent the three dimensional landscape. These data types have been utilized as ancillary data for machine learning algorithms to produce more accurate high resolution urban land cover maps embedded within the EPA EnviroAtlas (Pickard et al., 2015). Locational identification of these terrestrial natural and anthropogenic stressor sources using remotely sensed methods can inform issues in chemical safety, air and water pollution, sustainability, and urban heat island effects.

In addition to high resolution data access are the need for (1) supporting algorithm development to assist with classification, feature extraction, and QA editing, (2) the development of robust spectral libraries, and (3) the cyber-infrastructure for citizen science and crowd sourcing. EPA also seeks guidance from NASA and other federal agencies on long term scientific data management: best practices and standards for maintaining public access to data and products.

In this paper we have presented key challenges facing the EPA operational and research community with respect to terrestrial observations. These remote sensing challenges are pertinent to the current research planning effort within the EPA and operationally as the Agency responds to environmental impacts across the states and regions. Space-based observations in coordination with in situ measurements have proven invaluable with respect to assessing land cover change, vegetation dynamics and structure, etc. over the past 30 years and will continue to be a primary asset well into the next decade.

Literature Cited:

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