Human Health/Water Quality

***What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade*?**

The major key challenge for human health and water quality research in Earth System Science is the availability of satellite data sets that quantify strategic spectral characteristics of land, water, and atmosphere simultaneously from the visible through the thermal infrared spectrum. It is critical that these data provide sufficient spectral (i.e., channel selection and bandwidth), spatial, and temporal (e.g., satellite overpass repeat cycle and seasonal) resolutions to measure (directly or through algorithms) and to evaluate both environmental (state functions) and interface (process functions). This kind of Earth System Science data are critically important to understand vector borne and direct transmitted disease life cycles on a global scale within a regional and local habitat-host community context. Landscape epidemiology involves the integration of epidemiological data (active or passive surveillance data) with climate, environmental, and ecological data. Surveillance and response systems for public health are often based on case detection so that the epidemiologic unit is in fact the habitat-household. Data are then aggregated to community and regional scales. The use of satellite data sets combined with landscape epidemiology will provide an understanding of the relationships between ecology and infection and ultimately to predict the spatial and temporal distribution of pathogens, vectors, and/or hosts.

Key science questions and challenges are related to the ability to understand and quantify the environmental state and process functions that are significant in disease life cycles. The environmental state functions include precipitation, solar radiation, the surface energy budget which drives evapotranspiration, vapor pressure deficits, air, surface, and soil temperatures; and surface hydrology (flooding and water bodies). Process functions require the quantification of the thermodynamic and functional dynamics of ecosystems. These complex science questions require measurements of leaf level photosynthesis and biochemistry processes; CO_2 exchange; leaf nutrient content; temperature, and transpiration (energy budgets). At a larger scale the determination of leaf area index; canopy structure and architecture; nutrient and water cycles; phenology; identification of key species; and landscape scale ecological functional types are critical.

Currently existing satellites do not meet all of spectral, spatial, and temporal requirements to define and quantify the multi-factorial relationships among vector borne disease hosts, agents, vectors and the environment on a global scale. Planned missions such as NASA's Hyperspectral Infrared Imager (HyspIRI) is a global mission will provide continuous spectral measurements in the visible to short-wavelength infrared (VSWIR: 380 to 2510 nm) portion of the spectrum and measurements from eight discrete multi-spectral bands in the thermal infrared (TIR: 3 to 13 microns). HyspIRI addresses the needed spectral and spatial requirements for the study of vector borne diseases and other public health concerns. However, the temporal resolution of 16 days for the visible-short wave infrared and 5 days for the thermal is not sufficient to monitor dynamic public health concerns relating to disease out breaks. The impact of the longer repeat intervals is particularly critical in tropical regions and in areas with persistent cloud cover resulting in minimal or poor quality data coverage. Additional investments are needed to obtain shorter observation intervals. A simple solution is to use a constellation of satellites placed in orbit to give the required repeat intervals.

Land-based sources of pollution are increasingly becoming a threat for water quality not only for humans, but for ecosystems of watersheds (e.g., fish and riparian species), marshlands, freshwater bodies, and coastal (e.g., kelp forests, mangroves, sea grass, and coral reefs) areas. Further, communicable diseases associated with flooding (heavy rainfall and overflow of rivers) are of great concern with extreme weather events associated with climate variability. Water-borne diseases and vector-borne diseases having a life-cycle in water are a collective concern as clean water sources worldwide become more of a depleted resource. The need for fine spatial resolution (30 m or better) is relevant for measuring the variables associated with water quality in watersheds and coastal areas where communicable diseases are present. Also, high spatiotemporal resolution (4 m or finer and daily to weekly) is critical for capturing variability of coastal plumes and blooms and freshwater algal blooms relevant to communicable diseases associated with aquatic areas. The ability to provide satellite measurements in a range of spatial resolutions will enable integration of global-regional and habitat-household level data into scalable biology-based predictive models that factor-in the essential environmental and host behavioral drivers that control propagation and transmission of disease agents.

Both the satellite data sets and the derived data products need to be freely publically available on easily accessible portals with the capability to search specific satellite data sets and/or multiple types of satellite data in spectral space, time and in spatial context. It is also important that the data can be obtained either through a single individual search or from accessing the data by scripting for ingesting into routine data products.

A strong, well-funded applied sciences program is required to effectively link space-based observations to address the needs of broad-based user community. Many projects funded by NASA's Applied Sciences program have demonstrated that satellite observations can significantly enhance the capability of critical decision support systems in many public health applications. Typically, the majority of the costs associated with a satellite mission are incurred in mission development and infrastructure maintenance (operations and data systems) along with funding the scientific research. Only recently has NASA provided minimal support for applied scientists to be incorporated into the mission team. A significant outcome from this change is an early adopters program. The Soil Moisture Active Passive (SMAP) early adopters program was very successful in preparing both the scientific and applications community in the use of SMAP data. NASA's current applied sciences program is woefully underfunded. Funding levels need to be increased significantly to successfully address the societal public health challenges with the incorporation of satellite data.

Application of satellite data products in public health has exhibited great promise for prospective forecasting of vector borne disease outbreaks, opening the door for public health intervention, thus providing many potentially significant economic and societal benefits to the world. Attaining this potential presents a complex challenge that requires a multidisciplinary approach involving a broad scientific community. Researchers in the public health fields, climate science, ecology, hydrology, agriculture, meteorology, and information science are just a few of the scientific communities participating. Additionally, scientists from social, political, and economics fields are a critical component.

Why are these challenge/questions timely to address now especially with respect to readiness?

Vector borne diseases are emerging and re-emerging on a global scale. Vector-borne diseases were once a major public health concern only in tropical and subtropical areas, but today they are also an emerging threat for the continental and developed countries. Vector-borne diseases are among the most complex of all infectious diseases to prevent and control. Not only is it difficult to predict the habits of the vectors, but most vector-borne agents can infect animals as well. A recent example for the US has been the, rapid, unstoppable spread of West Nile virus (WNV). Another is Dengue fever which causes thousands of cases of illness in U.S. territories and U.S. travelers, and millions of cases worldwide. The globalization of many country's regional economies, climate variability, and civil unrest have spurred rapid movements of large human populations along with many of the disease vectors and reservoirs. Landscape scale alteration in ecosystems and land use impact the distribution of vector habitat and their interaction with human populations. Witness the worldwide problems caused by the recent Ebola outbreak resulting in a firestorm of political reactions over proposing quarantine or travel bans. Populations can migrate for economic reasons if the environment changes in such a way to reduce their ability to harvest plants or animals. People may migrate with their parasites. Monitoring changes in the environment and understanding how this affects the economy of an area is another important application for space-based observations.

The existing use of satellite observations in forecasting and monitoring vector borne diseases epidemiology has been successfully utilized for a limited number of vector borne diseases. A good example is use in predicting Rif Valley fever outbreaks which erupts in a 7-15-year cycle. A combination of passive (Landsat) and active (SAR) remote sensing data products are used to evaluate flooding and vegetation changes related to the outbreaks. Currently, the research suggests that early warning, weeks to months in advance of disease emergence, may be possible for RVF. Currently existing satellites do not meet all of spectral, spatial, and temporal requirements to define and quantify these significant multi-factorial relationships affecting vector borne disease life cycles.

Why are space-based observations fundamental to addressing these challenges/questions?

The problems we face with human diseases are of a global nature but impact human populations on a local and regional scale. The epidemiological processes in diseases are complex and occur over a vast range of scales, from regional to habitat-household scale for individual agents. Space-based observations provide *measurements of environmental state functions* and the *interfaces as process functions* important to vector and disease life cycles (within vector) and are measured within spatial context to provide provide a time series of measurements globally. Many critical environmental data sets are not available due to a multitude of factors ranging from remoteness and accessibility to the areas of interest, lack of resources in underdeveloped countries for ground based monitoring, and civil strife. Characterization of ecosystem structure and functioning on a landscape scale can only be determined using remote sensing.

Space-based observations can facilitate understanding how environmental variability is associated with not just vector-borne disease but a wide range of other important health issues. Local ecosystems are tightly associated with exposure to bacteria, viruses, protozoa and *Helminth sp*. infections that are directly transmitted from soil or water phases without a vector. E.g. Seasonal variation in cases of cholera and typhoid caused by increases in the height of the water table which leads to an increased contamination of water courses with fecal matter from both and humans. Geohelminth infections including hookworms are present in the soil in areas of open defecation or poor sanitation infrastructure. The viability of eggs produced by worms is tightly associated with environmental conditions, so as the environment changes, so does the risk of transmission of helminthiasis infections.