Earth Observations for Health (EO4HEALTH) Initiative
2020-2022 Implementation Plan

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Executive Summary

The use of Earth observation (EO) data among interdisciplinary and multi-agency teams can significantly advance scientific knowledge of existing public health threats to human, animal, and ecosystem health. The analysis of these geospatial data can enhance our understanding of the dynamic processes of the surrounding ecosystem and influence on human health. These data can also support disease preparedness and response actions in disease epidemic or humanitarian efforts.

The Earth Observations for Health (EO4HEALTH) Initiative will serve as a global network of governments, organizations, and observers, who seek to use EO data to improve health decision-making at the international, regional, country, and district levels. The overall goal is to support the systematic collection, analysis, and application of relevant information about areas of impending risk that inform the development of strategic responses to anticipate risks and opportunities and their evolution and communicate options to critical actors for the purposes of decision-making and response. The objectives to achieve this goal include:

- Objective 1: Engage with end-user communities to better understand and identify their needs and requirements.
- Objective 2: Develop and implement activities that address the needs and requirements of end-user communities.
- Objective 3: Improve the use of, and clarify future needs for, EO for health.
- Objective 4: Examine effectiveness and provide feedback on future EO actions for health.
- Objective 5: Participate with other individuals or Group on Earth Observations (GEO) communities of practice or institutions to produce an outcome greater than that achievable otherwise.

As a GEO Initiative, EO4HEALTH will help to foster the development of integrated information systems (IIS) that improve the capacity to predict, respond to, and reduce environment-related health risks. These systems combine EO monitoring and prediction; social, demographic, and health information; interdisciplinary research; application and assessment; communication; education; and training in order to enhance preparedness and resilience. Three initial focus areas are weather and climate extremes (e.g., heat), water-related illness (e.g., cholera), and vector-borne disease (e.g., dengue, malaria).

EO4HEALTH has supported the GEO Health Community of Practice (CoP) in the development and elaboration of the CoP Work Plan. The CoP Work Plan will be aligned with the EO4HEALTH objectives and include working groups on seven specific topics: 1) heat; 2) infectious diseases; 3) air quality; 4) food security and safety; 5) health care infrastructure; 6) cross-cutting issues; and 7) integrating EO data techniques.

Previous work within the GEO Health CoP has been focused on health early warning systems for air quality, heat, infectious disease, water-related illness, and ecosystem-related health impacts. Major foci included air quality (AirNOW International, Persistent Organic Pollutants), cholera, dengue, harmful algal blooms, leptospirosis, malaria, and meningitis. The GEO Health CoP seeks to expand on this previous work and focus on developing IISs that sustain engagement between scientists and decision makers to provide useful EO data that protect health and build resilience. The GEO Health CoP also seeks to build partnerships across public and private sectors, and to stimulate innovative and open approaches to gathering and providing useful risk assessment, monitoring, prediction, and forecasting information.

EO4HEALTH has leveraged the continued development of global networks of stakeholders that enhance shared scientific findings and promotion of EO tools and data. EO4HEALTH participants currently include representatives across the public and private sector, such as academic institutions, nongovernmental organizations, nonprofit organizations, private companies, and state, federal, and international governmental agencies. Over the next year, EO4HEALTH will continue to promote interdisciplinary collaborations by expanding scientific connections and partnerships with the public health community. Over the next three years, EO4HEALTH will also support the related GEO activities and tasks that aim to strengthen the use of Earth observation data for health decision-making.

The Co-Chairs of EO4HEALTH are John Haynes (National Aeronautics and Space Administration, NASA, USA) (jhaynes@nasa.gov) and Juli Trtanj (National Oceanographic and Atmospheric Administration, NOAA, USA) (juli.trtanj@noaa.gov).

1. Purpose

The use of Earth observation (EO) data among interdisciplinary and multi-agency teams can significantly advance scientific knowledge of existing public health threats to human, animal, and ecosystem health. The analysis of these geospatial data can enhance our understanding of the dynamic processes of the surrounding ecosystem and influence on human health. These data can also support disease preparedness and response actions in disease epidemic or humanitarian efforts.

1.1 Importance of Earth Observations for Health to the Group on Earth Observations

The use of EO data to improve health decision-making is related to a number of social benefit areas identified in the GEO 2016-2025 Strategic Plan:[1]

- Disaster Resilience
- Food Security and Sustainable Agriculture
- Public Health Surveillance
- Sustainable Urban Development

GEO aims to support the implementation of the Sustainable Development Goals (SDG) and policy recommendations of the United Nations (UN) 2030 Agenda for Sustainable Development and the Sendai Framework for Disaster Risk Reduction 2015-2030.[2,3] As such, EO for health that inform early warning to early action are relevant for monitoring progress towards SDG 3 (*Ensure healthy lives and promote well-being for all at all ages*), focusing on targets 3.3, 3.9, and 3.d.[4]

- SDG Target 3.3: By 2030, end the epidemics of Acquired Immunodeficiency Syndrome (AIDS), tuberculosis, malaria, and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases.
- SDG Target 3.9: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
- SDG Target 3.d: Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks.

Using EO for health are instrumental in disaster risk reduction and relevant for tracking progress toward the Sendai Framework for Disaster Risk Reduction. Changes in biodiversity, land use, and land degradation can influence health outcomes. Big data - artificial intelligence intersection, combined with advances in bioinformatics, analytics, and modeling, are increasingly applied to improve health outcomes. Hence, the availability of early warning systems can improve health outcomes and resilience of persons and communities, focusing on target g and priority 3.[3]

- Target g: Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030.
- Priority 3. Investing in disaster risk reduction for resilience: Public and private investment in disaster risk prevention and reduction through structural and non-structural measures are essential to enhance the economic, social, health and cultural resilience of persons, communities, countries and their assets, as well as the environment.

The World Health Organization (WHO) has identified the changing climate as one of the most important health risks of the future. The WHO Work Plan on Climate Change and Health for 2014-2019 states four objectives, which include strengthening scientific partnerships to support climate and health initiatives, increasing awareness on climate-health links, encouraging the generation of evidence-based scientific information, and offering technical support on related topics.[5] Notably, this work plan adds to the preceding work plan of 2009-2014, by emphasizing the need for innovative tools to improve systematic data collection of country-specific information and monitor progress of established objectives. These innovative data and tools include the use of space-based geospatial information in health applications and technological advancements.[6]

Many countries, international organizations, and private entities are beginning to address the intersection of environment and health. Globally, there are several societies and communities of practice specific to certain aspects of the broader EO and health agenda. Hence, the development of the GEO Health CoP was designed to be the GEO venue where these communities convene, learn from each other, stimulate collaborative research that protects health—including human, animal and ecosystem health—and provide feedback into the critical EO needs and science gaps.

1.2 Mission

The mission of the Earth Observations for Health (EO4HEALTH) Initiative is to foster the development of integrated information systems (IIS) that improve the capacity to predict, respond to, and reduce environment-related health risks.

1.3 Goal and Objectives

The overall goal of the EO4HEALTH Initiative is to support the systematic collection, analysis, and application of relevant information about areas of impending risk that inform the development of strategic responses to anticipate risks and opportunities and their evolution and communicate options to critical actors for the purposes of decision-making and response.

The objectives to achieve this goal include:

- Objective 1: Engage with end-user communities to better understand and identify their needs and requirements.

- Objective 2: Develop and implement activities that address the needs and requirements of end-user communities.

- Objective 3: Improve the use of, and clarify future needs for, EO for health.

- Objective 4: Examine effectiveness and provide feedback on future EO actions for health.

- Objective 5: Participate with other individuals or Group on Earth Observations (GEO) communities of practice or institutions to produce an outcome greater than that achievable otherwise.

1.4 Description of Planned Activities

The EO4HEALTH Initiative's Implementation Work Plan aims to build on these previous GEO and GEO Health CoP efforts and knowledge, add new foci, activities and partners, and to the extent possible develop IIS on these new topics or themes. An IIS is a construct that institutionalizes components that 1) engage and define demand; 2) identify and develop EO data and other relevant health surveillance and information; 3) develop useful information for assessment, prediction, and prevention of health risks and health promotion; 4) uses, communicates, and assesses the information; and 5) evaluates effectiveness and provides feedback on science, observation, and action gaps.

The Implementation Work Plan will build on existing activities, projects, and funding, providing a construct that facilitates greater coordination, knowledge sharing, and engagement of science and health decision-making communities. The One Health framework, which promotes transdisciplinary collaborations to better understand the interlinking processes of human, animal, and environmental health, will be integrated throughout all activities.[7]

EO4HEALTH has supported the GEO Health CoP in the development and elaboration of the GEO Health CoP Work Plan draft. Planned activities will focus on specific tasks that support the health-related SDGs of targets 3.3, 3.9, and 3.d. Working groups will continue to identify and engage health partners, clarify and address health needs for capacity building, and identify and address EO and prediction gaps and needs. This project will be aligned with the EO4HEALTH objectives and include working groups on seven specific topics: 1) heat; 2) infectious diseases; 3) air quality; 4) food security and safety; 5) health care infrastructure; 6) cross-cutting issues; and 7) integrating EO data techniques.

Activities will include diverse applications, such as feasibility studies (e.g., testing and validation of proofs-of-concept of possible applications), development of data-fusion products with strong applications and applied research potential, demonstrations that complete the transition, adoption, and sustained use of EO, capacity building, and studies on value of EO for decision making, preparedness, response or resilience.

These activities will support GEO efforts and the GEO Work Programme activities. These efforts include:

- GEO Health CoP: The GEO Health CoP has three initial focus areas, including weather and climate extremes (e.g., heat), water-related illness (e.g., cholera), and vector-borne disease (e.g., dengue, malaria). These multidisciplinary scientific areas lend themselves to cross-collaborations and synergies among various GEO groups.

- AquaWatch: GEO AquaWatch has supported GEO Health CoP efforts through information sharing and access to water quality information (e.g., nutrients, chlorophyll a, plastic pollution) as well as offered scientific and technical expertise to provide recommendations on draft procedure and policy documents on related topics. Potential GEO collaboration synergies include mutual capacity building efforts and advocacy to effect policy changes within overlapping stakeholder groups and working group participants.

- Blue Planet: The GEO Health CoP is a partner of GEO Blue Planet's working group on water-associated diseases. GEO Blue Planet seeks to expand collaborations with the GEO Health CoP over the 2020-2022 Work Programme period, including those related to pollution and coastal hazards.

1.5 Participants and Contributors

EO4HEALTH participants currently include representatives across the public and private sector, such as academic institutions, nongovernmental organizations, nonprofit organizations, private companies, and state, federal, and international governmental agencies. Participants attend and contribute to the agenda of quarterly telecons, in-person conference meetings, and working group tasks and activities.

The EO4HEALTH Initiative intends to continue to seek and expand sustainable long-term connections or partnerships with the public health community. The initiative will expand efforts on relevant SDGs, connecting with other GEO Work Programme elements, including GEO Biodiversity Observation Network (GEO BON), Human Planet, GEO Global Water Sustainability (GEOGLOWS), and those regional efforts of the Global Earth Observation System of Systems (GEOSS) of Africa (AfriGEOSS), Americas (AmeriGEOSS), and Asia-Oceania (AOGEOSS).

1.6 Expected Outcomes

These EO4HEALTH activities will connect EO for health with vector-borne and infectious disease issues, challenges, and decision making through active partnerships with public health managers and supporting organizations. These activities will strengthen capacity building to enhance the knowledgeable use of EO for decision making. Project findings will also be disseminated to the scientific community and other stakeholders through quarterly telecons, virtual and in-person scientific conferences, and social media technology. Future opportunities for cross-collaboration between AquaWatch, Blue Planet, and GEO Health CoP have been identified to explore pathogen tracking with applications to sustainable fisheries and food safety among subsistence fishers.

2. Background and Previous Achievements

By strengthening and building on the framework of the EO4HEALTH Community Activity (Work Plan 2017-2019)[8], the EO4HEALTH Initiative (Implementation Plan 2020-2022) will help to foster the development of IISs that improve the capacity to predict, respond to, and reduce environment-related health risks. These systems combine EO monitoring and prediction; social, demographic, and health information; interdisciplinary research, application and assessment; and communication, education, and training in order to enhance preparedness and resilience. Three initial focus areas are weather and climate extremes (e.g., heat), water-related illness (e.g., cholera), and vector-borne disease (e.g., dengue, malaria).

2.1 Previous Achievements with GEO Health Community of Practice

EO4HEALTH has supported the robust working groups of the GEO Health CoP in the development and elaboration of the CoP Work Plan. These teams continue to identify and engage health partners, clarify and address health and training needs, and identify and address observation and prediction gaps and needs. This project will continue to be aligned with the EO4HEALTH objectives and include working groups on seven specific topics: 1) heat; 2) infectious diseases; 3) air quality; 4) food security and safety; 5) health care infrastructure; 6) cross-cutting issues; and 7) integrating EO data techniques.

Previous work within the GEO Health CoP has been focused on health early warning systems for air quality, heat, infectious disease, water-related illness, and ecosystem-related health impacts. Major foci included air quality (AirNOW International, Persistent Organic Pollutants), cholera, dengue, harmful algal blooms, leptospirosis, malaria, and meningitis. The GEO Health CoP seeks to expand on this previous work and focus on developing IISs that sustain engagement between scientists and decision makers to provide useful EO that protect health and build resilience. The GEO Health CoP also seeks to build partnerships across public and private sectors, and to stimulate innovative and open approaches to gathering and providing useful risk assessment, monitoring, prediction, and forecasting information.

In order to promote EO for health in scientific exchanges, the GEO Health CoP has coordinated quarterly telecons and in-person meetings with established agendas that meet the needs of the CoP members. A GEO Health CoP website was designed and launched in 2017, where upcoming activities, news, and other updates, calls for scientific publications, and funding opportunities can be shared with CoP members and the global community.[9]

The GEO Health CoP has engaged with several stakeholders. First, members have worked with Environmental Systems Research Institute (ESRI) in India to complete the Global Heat Health Information Network (GHHIN). Second, in order to bridge the gaps with the SDGs focused on biodiversity, members have collaborated with Blue Planet and the biodiversity tasks. Finally, they have worked directly with the Public Health Agency of Canada to develop the *One Earth-One Health Workshop: Contributions of Earth Observations to Public Health Practices*, held in June 2017, in Montreal, Canada.

2.2 Previous Achievements with Diverse Stakeholders

Over the past two years, EO4HEALTH tasks have incorporated capacity building for end-user communities, dissemination of project findings to diverse stakeholders, and support for stakeholder engagement in the use of EO for health. These tasks have included three main components:

EO4HEALTH has strengthened capacity building to enhance the knowledgeable use of EO for health decision making among end-user communities. To further this goal, EO4HEALTH partnered with the NASA Applied Remote Sensing Training (ARSET) online and in-person trainings on topics including harmful algal blooms, air quality, eco-forecasting, land cover, and hydrology.

EO4HEALTH has facilitated the dissemination of project findings and EO data and tools to the scientific community and public through diverse sources. To further this goal, NASA announced four funded EO4HEALTH projects, as part of the GEO Work Programme, at the GEO XIV Plenary in October 2017, held in Washington, DC. Several of these projects are in collaboration with regional efforts of the Global Earth Observation System of Systems (GEOSS) in Africa (AfriGEOSS) and Americas (AmeriGEOSS). Scientific sessions have been coordinated at various conferences through the year, where principal investigators presented project findings. Social media technology (e.g., Twitter, GEO Health CoP website) has also been used to disseminate scientific project findings and other global activities to diverse stakeholders. Some of these reports include the dissemination of research projects (e.g., Using EO Data to Forecast Cholera Outbreaks in Yemen), global conferences (e.g., WHO's First Global Conference on Air Pollution and Health), global reports (e.g., Air Pollution and Child Health: Prescribing Clean Air), and webinars (e.g., Webinar Series On Air Pollution Mitigation).

By providing the capacity-building training in EO for end-user communities and offering strategies to disseminate scientific findings through social media technology, scientific knowledge can be enhanced within the global community. Synergistically with other GEO initiatives, EO4HEALTH activities aim to expand the number of end-user communities of EO data as well as the diversity of disciplines (e.g., non-Earth science disciplines) that they represent.

3. Relationship to GEO Engagement Priorities and to other Work Programme Activities

The EO4HEALTH Initiative will serve as a global network of governments, organizations, and observers who seek to use EO data to improve health decision-making at the international, regional, country, and district levels. There is a need to develop appropriate tools and data to enable the health community to address public health needs related to EO products and technologies. This can facilitate the spatial, analytical, and timely solutions needed to make EO data and technology more accessible by the health community, especially for epidemiological analysis, risk modelling, surveillance, investigation and emergency management.

EO4HEALTH aims to develop activities and tasks that focus on SDG targets 3.3, 3.9, and 3.d as well as Sendai Framework for Disaster Risk Reduction target g and priority 3.[3,4] To address this gap, seven GEO Health CoP working groups were developed to facilitate the development and implementation of EO science and technology in the health sector across diverse environmental health topics. These working groups will work directly with the EO4HEALTH initiative.

3.1 Working Group Activities

Working Group 1
Topic: Heat: Predict and Prevent Heat-related Health Risks across Time Scales
Goal: Working Group 1 aims to build a globally relevant capacity to use EO to understand, predict, and reduce health risks from heat across time scales. Initial efforts will center on building a global mapping capability that conveys heat risk and identifies the most critical used or needed heat data, forecast or other EO information along with land cover and social vulnerability data.

Working Group 2
Topic: Infectious Disease: Predict and Prevent Environmentally-sensitive Infectious Diseases (focus on vector-borne and water-related diseases)
Goal: Working Group 2 aims to improve prediction and prevention systems for environmentally-sensitive infectious diseases to help reduce risks for human health by application of EO to decision-relevant risk monitoring, with particular focus on underserved communities. Two overarching goals are to: 1) develop the global mosquito and related environmental data mapping capacity to serve as the EO backbone for building IISs for multiple mosquito-borne diseases and to support the ongoing GLOBE Mosquito mapping effort; and 2) develop an IIS for the monitoring and prediction of pathogen and toxin (*Vibrio* spp.) risk in marine and coastal environments coupled with critical EO-derived coastal and inland water quality.

Working Group 3
Topic: Air Quality, Wildfires, Respiratory Health
Goal: Working Group 3 aims to identify components and a modeling framework that would enable development of space-time specific assessments, monitoring, and forecasts quantifying the levels of exposure of populations to wildfire-related pollutants and aeroallergens associated with those levels of risk for various population groups.

Working Group 4
Topic: Food Security and Safety
Goal: Working Group 4 aims to strengthen EO applications to address food- and water-borne diseases that undermine health and food safety and security. A second goal is to develop an IIS for the monitoring and prediction of pathogen and toxin (*Vibrio* spp. and harmful algal blooms) risk in marine and coastal environments coupled with critical EO-derived coastal and inland water quality.

Working Group 5
Topic: Health Care Infrastructure
Goal: Working Group 5 aims to: 1) develop a partnership with UN agencies (WHO; UN Office for Disaster Risk Reduction, UNISDR; UN Environment Programme, UNEP) and governmental agencies (Australia, Canada, China, European Union, India, United Kingdom, United States) that share an interest in better identifying health care facilities at risk from environmental stressors and extreme weather events; 2) integrate EO datasets in order to develop an informational resource that can assess the vulnerability of health care infrastructures to local environmental stressors; and 3) develop methods to assess the adequacy of these infrastructures under regional extreme catastrophes. These aims have implications for both real-time operations and for long-term health adaptation planning.

Working Group 6
Topic: Cross-Cutting Issues: Regional Foci, Vulnerable Populations, Data/Access – especially concerning Health, Capacity Building and Training
Goal: Working Group 6 aims to increase awareness of using EOs with other data to prevent and respond to health-related problems.

Working Group 7
Topic: Integrating EO-based Population and Data Disaggregation Techniques in One Health Tools and Projects
Goal: Working Group 7 aims to identify authoritative reference data, missing information, and assessment of capacity of GEO to provide human and animal data and methods to answer the need for the health community.

These seven working groups will support GEO efforts, where linkages will be facilitated by the GEO Health CoP to support the implementation and sustainability of the EO4HEALTH framework and respective activities. Future engagement will incorporate collaborations with GEO health-related flagships (e.g., GEO Biodiversity Observation Network, GEO BON; GEO Global Agricultural Monitoring, GEOGLAM; GEO System for Mercury, GOS4M), initiatives (e.g., AfriGEOSS; AmeriGEOSS; AOGEOSS; AquaWatch; Blue Planet) and Community Activities (e.g., AIRNOW International; Copernicus Atmospheric Monitoring Service; Harmful Algal Bloom Early Warning System), in efforts to achieve objectives that focus on SDG targets and Sendai Framework priorities and targets.

3.2 EO4HEALTH Projects

As part of the GEO Work Programme, four EO4HEALTH projects were selected at the GEO XIV Plenary, held in October 2017, in Washington D.C. These projects, which use EO data and technology to support project objectives and GEO efforts, include:

- *Myanmar Malaria Early Warning System* (Tatiana Loboda, University of Maryland, College Park)

- *Environmental Determinants of Enteric Infectious Disease* (Ben Zaitchik, Johns Hopkins University)
- *Predictive Assessment of Transmission Conditions of Cholera in the Environment and Human Population using Earth Observations* (Antarpreet Jutla, West Virginia University)
- *GeoHealth: A Geospatial Surveillance and Response System Resource for Vector Borne Disease in the Americas* (John Malone, Louisiana State University and A&M College)

4. Stakeholder Engagement and Capacity Building

EO4HEALTH has leveraged the continued development of global networks of stakeholders that enhance shared scientific findings and promotion of EO tools and data. Over time, by identifying the needs and requirements of end-user communities, the development and implementation of capacity building activities can improve the future use of EO for health.

4.1 Stakeholder Engagement

EO4HEALTH participants currently include representatives across the public and private sectors, such as academic institutions, nongovernmental organizations, nonprofit organizations, private companies, and state, federal, and international governmental agencies.

These key contributors and participants of international organizations represent essential elements that can support the implementation and sustainability of the EO4HEALTH framework. These groups include:

- GEO Health CoP
- AquaWatch
- Blue Planet
- GEO BON
- Human Planet
- GEOGLOWS
- AfriGEOSS
- AmeriGEOSS
- Global Earth Observation System of Systems (GEOSS) of Asia-Oceania (AOGEOSS)

4.2 Capacity Building Activities

Activities that aim to engage stakeholders in the EO4HEALTH Initiative aim to promote the use of EO data in health decision making. These activities will include stakeholders at the individual, organizational, and institutional levels, such as:

- <u>Individual capacity building</u>: EO4HEALTH will continue to disseminate news and activities to contributors and participants that highlight upcoming international conferences and meetings relevant to the Earth and health science communities. Also, EO4HEALTH will encourage short-term virtual or in-person continued education courses that can advance scientific and technical training of contributors and participants. For example, EO4HEALTH continues to promote the NASA Applied Remote Sensing Training (ARSET) online and in-person trainings on diverse environmental health topics, including harmful algal blooms, air quality, eco-forecasting, land cover, and hydrology.

- Organizational capacity building: EO4HEALTH will continue to disseminate EO data tools, services, and other resources of the United States' and international space-based remote sensing data sets. Some open access data sources include NASA's constellation of EO satellites through the NASA's Earth Science Data and Information System (EODIS) Distributed Active Archive Centers (DAACs) and the European Space Agency's Copernicus system. Additional examples include the NASA Health and Air Quality Applied Sciences Team (HAQAST) "one-stop shop" web feature, basic NASA tools (e.g., NASA Worldview, NASA Earth Observatory), and the GEO Health CoP website. These websites serve as prime strategies for public communication efforts that promote new team applied research, connects the team with stakeholder organizations, and offers a mechanism to communicate evidence-based science related to air quality and health to the public and professionals.

- Institutional capacity building: EO4HEALTH will continue to seek collaborations that promote the use of EO data and technology to diverse end-user communities. Through quarterly telecons and annual in-person meetings, GEO Health CoP working group tasks and other activities can facilitate communication and encourage the development of project proposals and other initiatives of researchers and practitioners across scientific disciplines, sectors, and institutions.

Over the next year, EO4HEALTH will continue to expand connections with those end-user communities of EO data who represent other countries, agencies, and non-Earth science disciplines. More specifically, EO4HEALTH aims to seek linkages with the public health community, in efforts to strengthen capacity building that enhance the knowledgeable use of EO for health decision-making.

5. Management and Governance

The EO4HEALTH organizational chart is illustrated in Figure 1. The components of this chart serve as integral links to strengthen the framework of the EO4HEALTH Initiative. These components include:

EO4HEALTH Co-Chair Leadership: With the guidance of the GEO Secretariat, this Co-Chair Leadership will be instrumental to provide scientific expertise, technical coordination, and programmatic support for the EO4HEALTH Initiative.

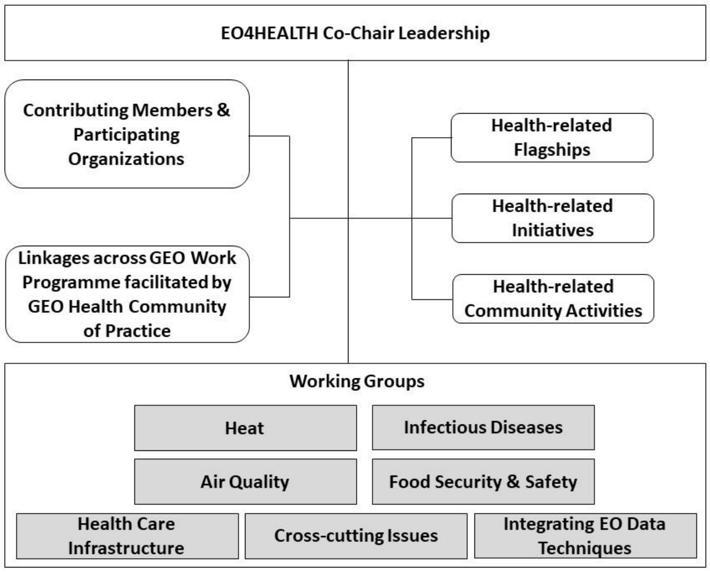
Contributing Members and Participating Organizations: These contributing members (e.g., Bangladesh, Canada, Ethiopia, Germany, Japan, Mexico, South Africa) and participating organizations (e.g., WHO; World Meteorological Organization, WMO) will provide scientific and technical expertise as well as facilitate an open dialogue for interdisciplinary collaborations using EO for health.

Linkages across GEO Work Programme: These linkages, facilitated by GEO Health CoP, will support the implementation and sustainability of the EO4HEALTH framework, including mission, goals, objectives, and activities.

GEO Health-related Flagships, Initiatives, and Community Activities: These GEO health-related flagships (e.g., GEO BON, GEOGLAM, GOS4M) will serve as well-defined stakeholder and user groups with long-term sustainable goals and support within the GEO community. These GEO health-related initiatives (e.g., AfriGEOSS; AmeriGEOSS; AOGEOSS; AquaWatch; Blue Planet) will facilitate coordinated actions and contributions toward achievement of established goals. These GEO health-related Community Activities (e.g., AIRNOW International; Copernicus Atmospheric Monitoring Service; Harmful Algal Bloom Early Warning System) facilitate the identification of end-user needs and examine scientific and technical logistics in health applications.

Working Groups: EO4HEALTH will leverage the seven Working Groups of the GEO Health CoP where contributing members and participating organizations can provide scientific and technical expertise on selected health-related topics for specific project tasks, projects, and activities.

Figure 1. The governance structure of EO4HEALTH.



The communication strategy with participants and stakeholders of the EO4HEALTH Initiative will be through the GEO portal, GEO Health CoP website, and the GEO Health CoP listserv. The GEO Health CoP website was designed and developed in 2017 and is continuously updated for activities, opportunities, and resources. Interested persons to join the GEO Health CoP can complete the website form. These sources will allow EO4HEALTH to share the results of projects and activities with the GEO community.

6. Resources

The EO4HEALTH Initiative is supported by the financial contributions (US$2.4 million) of the National Aeronautics and Space Administration (NASA), based in Washington, DC (USA). Additional support through in-kind participation and contributions of other resources includes six organizations: National Oceanographic and Atmospheric Administration (NOAA) (USA); Public Health Agency of Canada (Canada); Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (Fraunhofer IOSB) (Germany); WHO (Switzerland); WMO (Switzerland); and Global Framework for Climate Services (CFCS) (Switzerland).

EO4HEALTH will seek additional resources to support the planned activities during the 2020-2022 time period.

7. Technical Synopsis

The EO4HEALTH Initiative will promote the use of EO data and technology sources that are openly and freely accessible to the general community. These open access sources include data from the United States' and international space-based remote sensing data sets, including NASA's constellation of EO satellites through the NASA's EODIS DAACs and European Space Agency's Copernicus system. Additional examples are NASA ARSET online and in-person trainings on diverse environmental health topics, NASA Health and Air Quality Applied Sciences Team (HAQAST) "one-stop shop" web feature (e.g., NASA Worldview, NASA Earth Observatory), and the GEO Health CoP website. Contributors and participants will be encouraged to share their resources in efforts to achieve established goals and objectives for the 2020-2022 time period.

EO4HEALTH will seek additional data and technology sources to support the planned activities during the 2020-2022 time period.

8. Data Management and Policy

The EO4HEALTH Initiative will follow and promote the established GEOSS Data Sharing Principles and GEOSS Data Management Principles.[10,11]. EO4HEALTH aims to collaborate and engage with contributors and participants of various GEO initiatives in order to better understand the data needs and access requirements of the end-user community. By identifying these gaps, activities and other tasks can be developed to strengthen capacity building within the end-user community and enhance the knowledgeable use of EO for their health-related decision-making. Existing data platforms, supported by their respective institutions, will continue to be monitored, managed, and shared with the end-user community. Over the next few years, EO4HEALTH intends to coordinate data, tools, and other resources produced by the initiative, to strengthen GEO efforts and activities.

Annex A – Acronyms and Abbreviations

AfriGEOSS	African segment of Global Earth Observation System of Systems
AIDS	Acquired Immunodeficiency Syndrome
AmeriGEOSS	Americas segment of Global Earth Observation System of Systems
AOGEOSS	Asia-Oceania segment of Global Earth Observation System of Systems
ARSET	Applied Remote Sensing Training
CFCS	Global Framework for Climate Services
CoP	Community of Practice
DAAC	Distributed Active Archive Centers
EO	Earth Observations
EO4HEALTH	Earth Observations for Health
EODIS	Earth Science Data and Information System
ESRI	Environmental Systems Research Institute
GEO	Group on Earth Observations
GEO BON	Group on Earth Observations Biodiversity Observation Network
GEOGLAM	Group on Earth Observations Global Agricultural Monitoring
GEOSS	Global Earth Observation System of Systems
GHHIN	Global Heat Health Information Network
GLOBE	Global Learning and Observations to Benefit the Environment Program
GOS4M	Global Observation System for Mercury
HAQAST	Health and Air Quality Applied Sciences Team
IIS	Integrated Information Systems
IOSB	Institute of Optronics, System Technologies and Image Exploitation
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
SDG	Sustainable Development Goals
UCAR	University Corporation for Atmospheric Research
UN	United Nations
UNEP	United Nations Environment Programme
UNISDR	United Nations Office for Disaster Risk Reduction
WHO	World Health Organization
WMO	World Meteorological Organization

Annex B – List of References

[1] Group on Earth Observations. GEO strategic plan 2016-2025: implementing GEOSS. Group on Earth Observations. Geneva, Switzerland, 2015. https://www.earthobservations.org/documents/GEO_Strategic_Plan_2016_2025_Implementing_GEOSS.pdf

[2] United Nations. Transforming our world: the 2030 agenda for sustainable development. 2015. https://sustainabledevelopment.un.org/post2015/transformingourworld/publication

[3] United Nations, Office for Disaster Risk Reduction. Sendai Framework for Disaster Risk Reduction 2015-2030. 2015. http://www.unisdr.org/we/coordinate/sendai-framework

[4] United Nations. 2019. SDG 3: Ensure healthy lives and promote wellbeing for all at all ages. https://www.who.int/sdg/targets/en/

[5] World Health Organization. WHO workplan on climate change and health – aims and objectives: 2014-2019. 2015. https://www.who.int/globalchange/health_policy/climate-change-and-health-workplan-2014-2019.pdf

[6] Krishnamurthy RS, Hatton J. Space science and technologies to advance health-related sustainable development goals. *Bull World Health Organ*. 2018;96(1):3-3A.

[7] World Health Organization. One health. 2017. https://www.who.int/features/qa/one-health/en/

[8] Group on Earth Observations. GEO 2017-2019 Work Programme: Earth observations for health (EO4HEALTH). Geneva, Switzerland, 2016. URL https://www.earthobservations.org/activity.php?id=143

[9] Group on Earth Observations Health Community of Practice. Using environmental observations to improve health decision-making. 2017. http://www.geohealthcop.org/

[10] Group on Earth Observations. GEOSS data sharing action plan. 2010. https://www.earthobservations.org/documents/geo_vii/07_GEOSS%20Data%20Sharing%20Action%20Plan%20Rev2.pdf

[11] Group on Earth Observations. Data management principles implementation guidelines. 2015. https://www.earthobservations.org/documents/geo_xii/GEO-XII_10_Data%20Management%20Principles%20Implementation%20Guidelines.pdf

Annex C – Biographies of Project Leaders

John Haynes

John Haynes serves as Program Manager for Health and Air Quality Applications in the Applied Sciences Program of the NASA Earth Science Division at Headquarters in Washington, DC. He entered NASA Headquarters in 2002 through the Presidential Management Fellowship (PMF) program. As required by the PMF program, John completed two detail assignments during his fellowship (NOAA and the US House of Representatives). John converted to a civil service position at NASA Headquarters in August 2004 upon graduation from the PMF program.

John graduated from the University of South Alabama in 1999 with a B.S. in meteorology. In 2002, he graduated with an M.S. in meteorology from the University of Oklahoma. The first portion of his thesis work ("Analysis of Warm Season Morning Convection across the Southern Great Plains") was published in the December 2003 edition of Weather and Forecasting. The second portion of his thesis work ("The Evolution of Morning Convective Systems over the U. S. Great Plains during the Warm Season. Part II: A Climatology and the Influence of Environmental Factors) was published in the March 2008 edition of Monthly Weather Review.

John has received several awards during his tenure at NASA including a NASA Aviation Safety and Security Program Award, two NASA Group Achievement Awards, a One NASA Award, and a 2017 Team Excellence Award. In 2006, John was honored by his alma mater (the University of South Alabama) as an Exceptional Alumnus of the School of Meteorology.

Juli Trtanj

Juli Trtanj is the One Health and Integrated Climate and Weather Extremes Research Lead for NOAA. She is responsible for developing and implementing the National Oceanic and Atmospheric Administration (NOAA) Health Strategy across NOAA and with other federal, state, local and international Agencies, academic and private sector partners. She is leading efforts to build the National Integrated Heat Health Information System (NIHHIS) in partnership with the Centers for Disease Control, FEMA, OSHA, NIOSH, ASPR, EPA and other agencies. She coordinates the NOAA One Health Working Group, which brings together NOAA data, research, information and actions to inform health decision making. She started the first multidisciplinary and multi-partner research program on Climate Variability and Human Health. She developed and directed NOAA's Oceans and Human Health Initiative focused on Early Warning Systems, Health Benefits from the Sea, and Graduate Training.

Juli co-chairs the US Global Change Research Program, Climate Change and Human Health Group (CCHHG) and represents NOAA on the Pandemic Prediction and Forecasting Science and Technology Working Group. She an author on the Fourth National Climate Assessment, served on the Steering Committee of the USGCRP Climate and Health Assessment and was a Convening Lead Author for the Water-Related Illness chapter. She is the Integrated Information System for Health Lead for the Group on Earth Observations (GEO), and is directly involved with the World Health Organization (WHO), and other partners in the development of the Integrated Information Systems for heat, cholera and other water-related illnesses. She has contributed to, reviewed, or edited sections of several IPCC and US National Climate Assessment reports and authored several book chapters and journal articles.

Juli earned her Master in Environmental Science from Yale School of Forestry and Environmental Studies in 1994, and her Bachelors in 1986 from the University of California Santa Barbara.

Annex D – Addresses of Project Leadership and Secretariat Staff

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Annex E – Working Group Membership

Working Group 1 – Heat: Predict and Prevent Heat-related Health Risks across Time Scales)

- Co-Chair:
  - Ben Zaitchik, Johns Hopkins University
- Members:
  - Didier Davignon, Meteorological Service of Canada (Canada)
  - Paula Fievez, FrontierSI (Australia)
  - Gary Foley, Environmental Protection Agency (retired) (USA)
  - Michael Gebreslasie, University of KwaZulu-Natal (South Africa)
  - Steven Pawson, NASA Goddard (USA)
  - Andreas SkouloudisJoint Research Centre (Italy)

Working Group 2 – Infectious Disease: Predict and Prevent Environmentally-sensitive Infectious Diseases (focus on vector-borne and water-related diseases)

- Co-Chair:
  - Antarpreet Jutla, West Virginia University
- Members:
  - Stéphanie Brazeau, Public Health Agency of Canada (Canada)
  - Josh Colston, Johns Hopkins University (USA)
  - Paula Fievez, FrontierSI (Australia)
  - Michael Gebreslasie, University of KwaZulu-Natal (South Africa)
  - Josh Glasser, U.S. Department of State (USA)
  - Mike Gill, GEO Biodiversity Observation Network (Switzerland)
  - Dorian Janney, NASA Goddard (USA)
  - Tatiana Loboda, University of Maryland, College Park (USA)
  - John Malone, Louisiana State University (USA)
  - Marie-Fanny Racault, Plymouth Marine Laboratory (United Kingdom)
  - Kristin Wegner, University Corporation for Atmospheric Research/GLOBE (USA)
  - Michael Wimberly, University of Oklahoma (USA)
  - Ben Zaitchik, John Hopkins University (USA)

Working Group 3 – Air Quality, Wildfires, Respiratory Health

- Co-Chair:
  - Tatiana Loboda, University of Maryland, College Park (USA)
- Members:
  - Didier Davignon, Meteorological Service of Canada (Canada)
  - Paula Fievez, FrontierSI (Australia)
  - Gary Foley, Environmental Protection Agency (retired) (USA)
  - Michael Gebreslasie, University of KwaZulu-Natal (South Africa)
  - Antarpreet Jutla, West Virginia University (USA)
  - Ramon Martinez, Pan American Health Organization (USA)
  - Andreas Skouloudis, Joint Research Centre (Italy)
  - Karin Troncoso Torrez, Pan American Health Organization (USA)

Working Group 4 – Food Security and Safety

- Co-Chair:
  - Josh Glasser, U.S. Department of State (USA)
- Members:
  - Josh Colston, John Hopkins University (USA)
  - Gary Foley, Environmental Protection Agency (retired) (USA)
  - Antarpreet Jutla, West Virginia University (USA)
  - Ben Zaitchik, John Hopkins University (USA)

Working Group 5 – Health Care Infrastructure

- Co-Chair:
  - Andreas Skouloudis, Joint Research Centre (Italy)
- Members:
  - John Balbus, National Institutes of Health (USA)

Working Group 6 – Cross-Cutting Issues: Regional Foci, Vulnerable Populations, Data/Access – especially concerning Health, Capacity Building, and Training

- Co-Chair:
  - Dorian Janney, NASA Goddard (USA)
- Members:
  - Stéphanie Brazeau, Public Health Agency of Canada (Canada)
  - Gary Foley, Environmental Protection Agency (retired) (USA)
  - Michael Gebreslasie, University of KwaZulu-Natal (South Africa)
  - Josh Glasser, U.S. Department of State (USA)
  - John Malone, Louisiana State University (USA)
  - Vince Seaman, Gates Foundation (USA)
  - Andreas Skouloudis, Joint Research Centre (Italy)

Working Group 7 – Integrating EO-based Population and Data Disaggregation Techniques in One-Health Tools and Projects

- Co-Chair:
  - Stéphanie Brazeau, Public Health Agency of Canada (Canada)
- Members:
  - Didier Davignon, Meteorological Service of Canada (Canada)
  - Paula Fievez, FrontierSI (Australia)
  - Gary Foley, Environmental Protection Agency (retired) (USA)
  - Michael Gebreslasie, University of KwaZulu-Natal (South Africa)
  - Josh Glasser, U.S. Department of State (USA)
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  - John Malone, Louisiana State University (USA)
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Annex F – Work Plan for GEO Health Community of Practice in support of EO4HEALTH Initiative

A. Heat: Predict and Prevent Heat-related Risks across Time Scales

Primary goal: The GEO Health CoP aims to reduce morbidity and mortality associated with extreme heat events and rising temperatures through reliable, decision-relevant integrated information systems, that include early warning, targeted to reduce heat impacts on vulnerable populations. This effort will focus on identifying, applying and documenting EO needs to reduce heat-related health risks. The goal is to build a globally relevant capacity to use EO to understand, predict, and reduce health risks from heat across time scales. Initial efforts will center on building a global mapping capability that conveys heat risk, identifies the most critical used or needed heat data, forecast or other EO information along with land cover and social vulnerability data. This weaves together many of the ongoing activities and outcomes within the CoP. This will also be done in close partnership and in support of the Global Heat Health Information Network (GHHIN), and other national IISs to bring the EO component into the GHHIN's broader global capacity, intervention, and action mapping effort. This goal resonates with a number of active efforts around the globe, including guidance included in the 2015 joint WMO/WHO report, *Heatwaves and Health: Guidance on Warning-System Development*.

Achieving this overarching goal requires progress on several broadly defined objectives. These include establishing evidence-based warning systems that address neighborhood-scale (~100s of meters) variability in heat conditions; identifying gaps and tracking progress in operational weather forecast capacities relevant to heat warning; where possible, extending the time horizon of decision-relevant heat forecasts; quantifying both acute and chronic impacts of heat exposure and integrating that information to warning systems; ensuring that warning systems and health interventions account for the multiple meteorological variables that contribute to heat exposure (temperature, humidity, and others); and facilitating access to generic heat-related health risk information by countries and communities with reduced technical resources.

Efforts relevant to these objectives are already well underway. At the scale of global coordination, this work includes the recent establishment of the GHHIN, which is designed to sustain engagement among decision makers, health practitioners, public health organizations, and scientists across multiple sectors to accelerate knowledge and action that reduces health risks of extreme and ambient heat on multiple time scales. The 100 Resilient Cities (100RC) initiative provides an additional forum for exchange on the particularly critical issue of heat mitigation and adaptation in urban environments. Within specific countries, initiatives such as the United States focused National Integrated Heat Health Information System provide targeted heat risk management applications. In the GEO community, the continued and growing collection and stewardship of heat-relevant EOs offers a tremendous opportunity for learning and application.

Outcomes: Building from these existing efforts, the GEO Health CoP aims to achieve a number of specific outcomes in the coming 1-5 years:

- Document existing hazards and proposed methods for triggering appropriate warnings and response during extreme heat events, including context-relevant application of EO.
- Apply EO in combination with local demographic and socio-economic information to operationalize spatially explicit vulnerability assessment and warning systems at kilometer or sub-kilometer scale.
- Track progress in forecast-based heat warnings by creating a living document or online forum for the research and applications communities. This forum will address critical issues such as extended time horizon (subseasonal to seasonal) forecasts, communication of forecast

uncertainty, identification of decision-relevant forecast targets, and coordination on post-forecast evaluation.

- Integrate use of microclimate monitoring, satellite-based health estimates and modeling of outdoor heat conditions to inform heat warning systems and urban planning and project future heat wave risk using downscaled climate models. Apply these tools to operational warning systems in selected pilot studies.
- Perform heat-monitoring studies in informal settlements and other underserved communities in order to customize early warning systems to meet the needs of the most vulnerable.
- Monitor seasonality and trends in urban vegetation and other heat-relevant surface properties (albedo, emissivity, permeability) to advance understanding of heat variability and inform mitigation activities. Advance ongoing efforts to inventory urban land use at high resolution and physical detail in order to improve model representation of localized heat features.
- Increase the number of studies that integrate state of the art EO with dynamic population estimates and detailed records on population health and hospital admissions.
- Develop a global heat risk map based on climate, supported with specific focus studies in at least three to develop in depth decision tools that appropriately account for background climate and acclimatization.
- Evaluate long-term heat risks projected by climate models relative to current operational heat alert triggers in different countries and climate zones.
- Estimate healthcare costs of heatwaves and benefits of a heat health warning and intervention, including prompt and spatially accurate allocation of health services for children under unexpected extreme weather conditions and air quality. This requires detailed studies across climate and development context, and should be applied to identify emerging heat risks as well as to characterize benefits under current conditions.
- Engage actively with GHHIN, 100RC, European Union's H2020 projects, and other relevant networks in order to ensure that EOs are used effectively and appropriately to advance their goals.

We note that the current activities and anticipated outcomes listed here are a partial list of heat-relevant research and operations going on across the globe. Ongoing coordination across the CoP will allow us to extend and to refine this list.

<u>Identification of critical EO and prediction requirements for health (e.g., What data and surveillance systems and tools are you currently using? What data and surveillance systems and tools do you need to be able to measure risk better for future projects?)</u> Sustained and enhanced EO are critical to improving prediction and prevention of heat-related health risks. One particularly critical class of EO is passive thermal infrared imagery that can be used to estimate radiometric land surface temperature. To be optimal for early warning systems at local scale, these observations should be as frequent as possible, and they should include daytime and nighttime measurements. The combination of high frequency low earth orbit and geostationary imagery at moderate resolution (0.5-3km) with less frequent high-resolution imagery (<100m) can support operational high-resolution mapping. As radiometric land surface temperature is not synonymous with air temperature, efforts to calibrate air temperature estimates using satellite data and in situ air temperature measurements can strengthen the link between EO and health-relevant temperature exposures. The Climate Hazards Group InfraRed Temperature with Stations (CHIRTS) product, in addition to MODIS-derived air temperature estimates, are important efforts to fill this need at global scale. At local scale, pairing satellite-derived radiometric temperature with micrometeorological in situ temperature measurements—particularly in heat vulnerable communities—is an emerging area of research transitioning to operations.

Beyond temperature, estimates of near-surface humidity are critical and are relatively underrepresented in EO datasets. The GEO Health CoP is working to fill this need. Estimates of heat must also be paired with estimates of population and vulnerability. EO of nighttime lights and of land cover can contribute to population estimates, and integration of these data to dynamic population models is a promising opportunity for improving exposure estimates. These methods must be trained using in situ population data, including studies of activity of different vulnerable populations during periods of high heat. Finally, the health impacts of heat are mediated by other environmental factors, in particular air quality indicators relevant to asthma, exacerbation of chronic pulmonary obstructive disorders (COPD), and other conditions relevant to heat sensitivity. Provision of warning systems that leverage EO for concurrent monitoring of heat and air quality are an emerging application area of particular relevance to health interventions.

B. Infectious Disease: Predict and Prevent Environmentally-sensitive Infectious Diseases (focus on vector-borne and water-related diseases)

Primary goal: Improve prediction and prevention systems for environmentally-sensitive infectious diseases to help reduce risks for human health by application of EO to decision-relevant risk monitoring, with particular focus on underserved communities. Two overarching goals are to: 1) develop the global mosquito and related environmental data mapping capacity to serve as the EO backbone for building IISs for multiple mosquito-borne diseases and to support the ongoing GLOBE Mosquito mapping effort; and 2) develop an IIS for the monitoring and prediction of pathogen and toxin (*Vibrio* spp.) risk in marine and coastal environments coupled with critical EO-derived coastal and inland water quality. This will be done in close partnership with ongoing efforts of Blue Planet and AquaWatch. These data may also then be relevant as indicators useful for the SDGs.

Outcomes:

- Build global health risk maps, develop health interpretation/risk prediction of subseasonal and seasonal climate outlooks .
- Enhance integrated modeling of disease risk or prediction of environmental drivers of disease and other health outcomes.
- Better understand links between environmental and climate change, food quality and nutrition, and health. Better understand the key drivers of diseases such as environmental, climatic, demographic, socio-economic or human behavioral changes. By understanding how the key drivers affect diseases, we may be able to predict when, how, and where diseases will emerge and identify the populations most at risk and most vulnerable.
- Use hydrometeorological parameters and environmental sensitivity to characterize the impact of climate on pediatric enteric infections (e.g., rotavirus, Campylobacter, Cryptosporidium) in low- and middle-income countries. Assess local risk of exposure to vector-borne or water-related diseases due to the effects of climate change and support public health intervention actions.
- Assess the utility and reliability of satellite and model-derived EO for disease risk monitoring and early warning in data poor environments.
- Explore influence of environmental and climate drivers on pathogens genetic diversity and development of anti-microbial resistance.
- Examine risk mapping (including "hotspots") and geospatial modeling of microbial contamination for vector-borne and water-related pathogens to strengthen the geospatial surveillance and response system resources.
- Promote open resource databases and models via the Internet, with training courses, to other investigators interested in mapping and modeling other vector-borne diseases.
- Identify interagency and institutional collaborations that bring together their concurrent capacities and expertise to improve the prediction, detection, and response to emerging zoonotic infectious diseases. Link activities with intergovernmental framework and agenda (e.g., 2015-2030 Sendai

Framework for Disaster Risk Reduction; 2030 Agenda for Sustainable Development; Paris Climate Agreement)

- Engage with health researchers and practitioners to increase the rate of in situ environmental monitoring at health study sites and in regions with high rates of vector-borne or water-borne disease
  - Vector-borne diseases:
    - Mosquito-borne (West Nile virus, Zika, Dengue, Malaria, Chikungunya, Yellow Fever), Tick-borne (Lyme disease), Hantavirus, Leishmaniasis
  - Water-borne diseases:
    - *E. coli,* Leptospirosis, Cholera and other *Vibrio* spp., Rotavirus, Campylobacter, Cryptosporidium, Hantavirus
  - Other pathogens:
    - Leishmaniasis, Avian Influenza (other airborne diseases affecting human health), Antimicrobial resistance (e.g., artemisinin resistance)

<u>Identification of critical EO and prediction requirements for health (e.g., What data and surveillance systems and tools are you currently using? What data and surveillance systems and tools do you need to be able to measure risk better for future projects?)</u>

- More consistent in situ weather and hydrological monitoring coordinated with epidemiological studies, in order to evaluate EO in context.
- Better satellite capabilities for monitoring water quality in coastal regions and small inland water bodies.
- Improved Subseasonal to Seasonal (S2S) hydrological forecasts.
- Use host of data from several satellite sensor [SMAP, MODIS (LST, NDVI), GPM and SRTM] data in comparison to WorldClim data to develop regional environmental suitability maps at various resolutions (1km^2, monthly).
- Examine feasibility of using sub-meter resolution Worldview 2 and Worldview 3 data is develop Habitat-Household scale risk models.
- Ocean-color data (e.g., reflectance at multiple wavelengths in the visible domain, chlorophyll-a, phytoplankton size fraction, turbidity), sea-surface temperature (SST), sea-surface height (SSH).
- Long-term, continuous, bias-corrected, climate-quality remote-sensing observations developed in the European Space Agency Climate Change Initiative (ESA CCI). In the ESA CCI Ocean Colour project, remote-sensing reflectance have been retrieved from multiple sensors (SeaWiFS, MODIS-Aqua, MERIS, VIIRS, and eventually OLCI); and 20-year time series have been generated, e.g., OC-CCI project at https://www.oceancolour.org/.
- Promote increased utilization of the GLOBE Observer Mosquito Habitat Mapper to identify mosquito larvae, eliminate breeding sites, and combine these data with satellite data to help predict outbreaks.
- Engage international public health organizations to help expand network of public health officials, organizations and schools in the GLOBE Zika Education and Prevention Project. GLOBE will introduce public health officials to GLOBE Country Coordinators so they can explore collaboration on the project to help support national and local public health objectives. In the local communities, public health officials can work with organizations and schools to understand and help mitigate local sources of disease-carrying mosquitoes using the GLOBE Mosquito Habitat Mapper app. Public health officials can present the project and availability of its crowd-sourced data to their colleagues at international, regional and national conferences and other meetings, in efforts to enable them to benefit from the project data and to partner with participants in the project.

C. Air Quality, Wildfires, and Respiratory Health

Primary goal: Identify components and a modeling framework that would enable development of space-time specific assessments, monitoring, and forecasts quantifying the levels of exposure of populations to wildfire-related pollutants and aeroallergens associated with those levels of risk for various population groups.

Outcomes:

- Understand and address the implications of changes in heat, wildfires, and aeroallergens on air quality and human health implications including loss of life due to wildfires.
- Model daily fire spread, associated emissions, and atmospheric transport of those emissions (by species) to build a model linking wildfire occurrence and characteristics with respiratory distress in population as reported by health care utilization (e.g., emergency room visits).
- Examine the finer granularity air quality data and modelling with COPD patient medication usage and physical movement through the neighborhood.
- Produce air quality forecasts with wildland fire emissions.
- Monitor and track smoke plumes.
- Measure sub-daily (e.g., hourly) fire spread and fire characteristics (e.g., Fire Radiative Power that is directly related to fuel consumption completeness and associated emissions) to quantify fire-related emissions by species, and link that to atmospheric transport.
- Evaluate the effects of agricultural and forestry management fires on health service utilization.
- Develop better fuel characterization maps to support more detailed tracking of speciation of the emissions including tracking of emerging pollutants and allergens.
- Propose appropriate verification standards to assess the accuracy of existing wildland fire smoke forecast systems, for surface level concentrations of pollutants and aeroallergens.
- Assess the performance of available tools and methods for wildfire pollution characterization developed in the United States, Canada, and European Union over the developing world (e.g., South and Latin America) to bolster existing fire-monitoring capabilities.
- Extend wildfire health outcomes studies to cover long-term repeated exposure.
- Extend the access and utilization of health data records beyond hospitalization and emergency room visits to capitalize on other data sources available at the regional and national scales (including GP reports, health clinic reports) to assess health outcomes beyond most acute responses reported through hospitalization and emergency room (ER) visits.

Identification of critical EO and prediction requirements for health (e.g., What data and surveillance systems and tools are you currently using? What data and surveillance systems and tools do you need to be able to measure risk better for future projects?)

Satellite-based observations and datasets:

1. Active fire detection and characterization (specifically MODIS and VIIRS active fire products with associated FRP measurements). Need to develop strong regional models for converting FRP to FRE – a time-integrated measurement of fire radiative energy (FRE) rather than an instantaneous observation of fire radiative power (FRP).
2. Daily-subdaily area burned measurements or forecasts. For historic fires, we can use existing burned area products and estimates of daily or subdaily fire progression within those (MCD64 – is a reasonable product but would rather have moderate resolution 30m Landsat-Sentinel-2-based burned area; however, no global datasets or any other operationally applied are available, although there is one under development). To develop forecasts or provide on-going monitoring, we need to have an ability to estimate/predict area burned. One of the possible solutions for that is

to use fire behavior models that both predict spatial extent as well as consumption of biomass using observed/predicted meteorological conditions, fuels, and terrain.

3. Need to develop specific regional relationships between satellite measurements of AOD and fire emissions. Possibly field based. From EO, we should decrease the complexity at larger scales, but be able to show increased complexity at the local level.
4. Need to develop normalized, mosaicked images. Cloud cover and latitudinal differences present a challenge for collecting clear observations and thus effective monitoring. Given these challenges, mosaicking normalized images from several subsequent observations may be more feasible than deriving one, clear image. The Harmonized Landsat Sentinel-2 product offers promise to address this need with revisit frequency of 2-3 days.
5. Need to develop methods to downscale data for air quality and wildfires.
6. Explore opportunities to replicate country-based monitoring systems with EO.

Atmospheric transport models:

1. Higher spatial resolution is needed for estimating meteorological conditions at multiple levels. Many atmospheric transport models operate on reanalysis meteorology, which generally has very coarse spatial resolution. However, multi-level vertical stratification is needed to ensure reasonable estimates of proper atmospheric mixing and transport. To support forecasts and projections, we need to be able to link numerical weather modeling outputs at better resolution to atmospheric transport models to ensure better precision of forecasts.
2. Combine wildland fire emission estimates with chemical data assimilation. The assimilation of satellite aerosol data at the global scale has been demonstrated as being mechanically possible, but more work is required to demonstrate an actual gain in the predictability of surface concentrations.

Health data records:

1. We need to enable wider access to syndromic surveillance data (ER visits). Wider access should help with understanding episodic exposure.
2. We need broader access to multi-year medical information records, including but not limited to information from general practitioners, pharmaceutical records, and medical consumption. Broader access should help with understanding persistent exposure (e.g., regions frequently and persistently impacted by elevated levels of fire-related pollutants). There are varying levels of accessibility to data records across country-level jurisdictions, but it is generally difficult to find high-quality health care data outside of epidemiological studies that use ER hospitalization data.
3. We need to have records at better than zip code level spatial granularity to support better estimates of exposure and risk.

New studies directly measuring impacts of exposure on outcomes:

1. There is a need to conduct medical studies that can link measured personal exposure levels to blood concentrations of the pollutants.
2. Examine the relationship between medicine consumption as a result of a fire event. There is preliminary research regarding the relationship between medicine consumption and a heat event.
3. There is a need to examine the impacts of PM2.5 from wildfire smoke on exposure levels, but it is challenging to obtain health data to correlate health outcomes with wildfire PM2.5.

D. Food Security and Safety – Vibrio and Harmful Algal Blooms (HABs), Mycotoxins, and Subsistence Hunting

Primary goal: Strengthen EO applications to address food- and water-borne diseases that undermine health and food safety/security. A second goal is to develop an IIS for the monitoring and prediction of pathogen and toxin (*Vibrio* spp. and harmful algal blooms) risk in marine and coastal environments coupled with critical EO-derived coastal and inland water quality.

Outcomes:

- Examine seasonal forecasts of food insecurity (in collaboration with the Famine Early Warning System) and systems analysis perspective to track the propagation of shocks to the food system across scales.
- Understand vulnerability and resilience options for poor households that suffer from a combination of chronic and acute food insecurity.
- Improve understanding of *Vibrio* spp. and harmful algal bloom events and strengthen early warning systems for affected coastal communities.

Identification of critical EO and prediction requirements for health (e.g., What data and surveillance systems and tools are you currently using?
Data sets currently used by the group include:

- Meteorological estimates from GLDAS and CHIRPS.
- Data on enteric pathogens from community-based and health-facility-based epidemiological studies.
- Data on water, sanitation, and health (WASH) coverage, especially in Africa.
- FEWSNet and related networks – for reliable and frequent earth observation of vegetation status, maps of cropped and fallow areas, satellite-derived rainfall in data scarce regions, satellite-derived and model-derived soil moisture estimates, satellite-derived and model-derived temperature estimates.
- Ocean and land observations for *Vibrio* spp. and harmful algal blooms.

What data and surveillance systems and tools do you need to be able to measure risk better for future projects?
A diverse set of responses to this question included:

1) Better processes to facilitate the flow of data and the generation of actionable information that gets into the right hands at the right scale at the right time.
2) Stronger multi-country epidemiological surveillance for key diseases such as severe diarrhea.
3) Higher-resolution weather forecasts (seasonal/sub-seasonal).
4) Better mapping of key social variables:
    a. WASH coverage across low- and middle-income countries, especially in Latin America and Asia.
    b. In situ data on ground and surface water from Africa and Asia.
    c. Human population estimates, including seasonal migration.
5) Better integration of EO data streams to achieve spatially and temporally complete and high-resolution monitoring of complex systems, including:
    a. Conditions relevant to crop yield.
    b. Coastal zone information related to sea surface temperature, chlorophyll, species-specific identification of harmful algal blooms, and hydrodynamics.

E. Health Care Infrastructure

The infrastructure associated with Health Care Facilities (HCF) are already subject to registering and reporting by national ministries of health and the WHO as part of the Global Health Observatory (GHO). Alas, GHO registries focus only on the “health-care perspectives”, with an emphasis on diagnostic equipment and therapeutic capabilities, and updates on an annual basis, at best. No information is included in such observatories about the “environmental stressors” of the local surroundings that are relevant to both direct causation of health effects as well as adverse impacts on the infrastructure of health care facilities, including vulnerability to flooding or extreme weather events.

Primary goals:

1. Develop a partnership with UN agencies (WHO, UNISDR, UNEP) and governmental agencies (Australia, Canada, China, European Union, India, United Kingdom, United States) that share an interest in better identifying health care facilities at risk from environmental stressors and extreme weather events. These partnerships may include existing efforts, like the WHO/PAHO SMART Hospital program, potential US military and other United States’ health care organizations, and the European Union.
2. Integrate EO datasets in order to develop an informational resource that can assess the vulnerability of health care infrastructures to local environmental stressors. Hence, examine the adequacy of HCF during seasonal loads and local population needs.
3. Develop methods to assess the adequacy of these infrastructures under regional extreme catastrophes. This has implications for both real-time operations and for long-term health adaptation planning. In this way, we can identify areas where additional humanitarian facilities will be necessary or neighboring HCF that might be able to assist in the relief of these extreme events and to assess the capacities of relief efforts.

Outcomes:

- Monitor (from satellites) the status and the exterior size of HCF signaling positive or negative area modifications for near-real-time alerts.
- Assess vulnerability of local HCF to local environmental stressors, including flooding, coastal storm surges and winds, wildfires, and threats to water supplies.
- Examine associations of the local HCF to environmentally induced diseases (e.g., severe heat waves, wildfire smoke events).
- Examine the adequacy of these facilities initially to annual variations.
- Extend the adequacy of HCF to seasonal variations since facilities might be adequately but not for monthly or seasonal peaks.
- Project and assess the risks during peaks and prepare a constellation of monitoring instrumentation to assess extreme environmental events inducing extraordinary peak in health treatments.
- Use in planning of humanitarian interventions.
- Assess the precautionary needs necessary from neighboring HCF or mobile units.

Prospective long-term knowledge

- Assessment of population health care capabilities associated with environmental exposure from classical toxic substances and the manufacturing and use of nanomaterials.
- Adequacy of health care infrastructure facilities under usual and acute events.
- Testing of health infrastructure needs during humanitarian interventions.
- Resilience using multidisciplinary knowledge with efforts from internationally operating teams.

Identification of critical EO:

The following are relevant EO that could be utilized immediately from various GEOSS surveillance sources:

1. High-resolution observations of land-use at the periphery of Global HCF.
2. Population density maps and real-time lights during nighttime.
3. Elevation and flood plain mapping.
4. Proximity of wildfire or open burning threats to air quality or to facility itself.

5. Where possible mapping of critical infrastructure, including electrical and fuel supplies, water supplies, and waste water removal and treatment.
6. Begin with a localized study and then make it available for everybody and identify the issues for adapting it to other locations.
7. One starting point may be real-time operational use, to assess damage to HCF comprehensively and to help guide relief and provision of emergency energy, food, and water services.
8. Observations from local environmental stressors for soil, water and air affect to population health.
9. Observations from the ground for local environmental parameters.
10. Establishment of a tool for suitable EO sensors able to cover a thematic window during a period of extreme events.

Finally, an assessment of infrastructure of primary and possibly secondary HCFs with capabilities can serve as a relevant instrument for health care applications. For example, the following table describes the infrastructural component and elements:

Infrastructural component	**Infrastructural elements in component (number of data queries)**
Facility and its management	Statistics (18)
	Maintenance (1)
	Accessibility (1)
	Information management (1)
	Services (9)
Physical infrastructure	Compound (2)
	Buildings - basic data (5)
	Buildings – construction (7)
	Buildings – interior works (6)
	Buildings – installations (6)
Supply facilities systems	Electrical supply (5)
	Water supply (5)
	Rain water harvesting (6)
Disposal systems	Waste (9)
	Effluent discharge (5)
Technical medical equipment	Asset location data (1)
	Asset statistical data (2)
	Asset functionality (2)
	Maintenance resources (2)
Information Communication Technology	Telecommunications (2)
	Internet (2)
Outreach services	Transport (2)
	Referral (2)

Possible implementation flow:

1) Global geo-positions of all HCF.
2) Automating an extraction module that could operate on google earth for the current size of facilities (2019-2020).
3) Incorporate the current health instrumentation as I think is at WHO and collaborate with the dynamic population density groups.
4) Incorporate the annual load of cases treated (up to 2020).
5) Item-2 could be advanced from EO (from multi EO satellites, United States, European Union, Australia, Japan, South Africa).
6) Incorporate the seasonal-monthly load of cases treated (up to 2022).
7) Start real emergency operations with a triggering mechanism on day-visible-light and with night-time energy consumptions (up to 2023).

There is clearly a role for EO in geo-locating health care facilities. However, it should be taken into consideration that implementation schemes might become complicated and different in different settings.

In developing countries with mostly public health care systems, this could be helpful, although it may not capture the informal health care services well. This information is probably already collected and available in such countries. In countries with advanced private health care system and security concerns, it will be difficult to use satellite imagery only. In addition, a comprehensive map of HCF's might not be possible to be open to the global community.

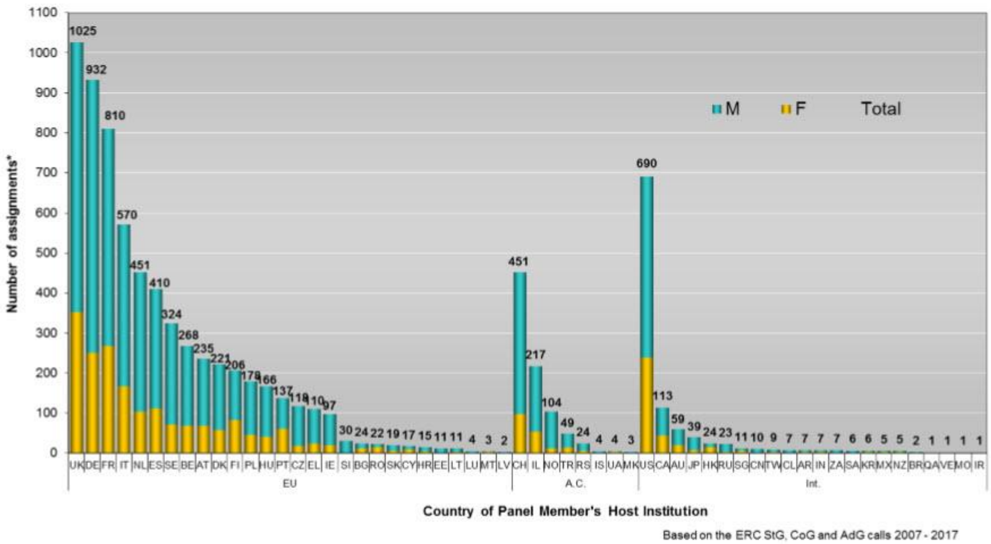
It is desirable to come up with an artificial intelligence (AI) algorithm to identify HCFs with some level of precision from visible images and geolocate them, we would still want and need more information on the HCFs in terms of vulnerability. EOs could be handy (e.g., are there solar panels or generators on the roof?), but there will be a need to advance the initial algorithm or standard as different vulnerability profile for an HCF will become essential for implementation in different countries. The following could be a starting place for a work plan, which should be properly adopted to support the needs of important institutions as NIEHS to the extent that the development is closely liaised with actual operations.

Fundraising

European Research Council (ERC) schemes of grants allow international involvement. The number of grants assigned is shown below with several from international countries for 2007-2017.

The operational ERC schemes are all for up to years with the following specifications:

- Starting Grants (2-7 years after PhD): up to 1.5 M€.
- Consolidator Grants (7-12 years after PhD): up to 2 M€.
- Advanced Grants (with record of significant research achievements in last 10 years): up to 2.5 M€.
- Proof-of-concept (bridging gap between research-earliest stage of marketable innovation): up to 150 k€ for ERC grant holders.
- Synergy Grants (2-4 Principal Investigators): up to 10 M€ for 6 years.



The aforementioned operations might fall under the mandate of UN Office for Disaster Risk Reduction (UNISDR) and the Sendai Framework for Disaster Risk Reduction 2015-2030.

Similar schemes for US or international grants could be:

- Robert Wood Johnson Foundation: This scheme is suitable for public agencies, universities, and public charities. Open calls can provide overall description of project funding (e.g., $150,000 to $350,000 budget range) and terms (e.g., 12-36 month range). For profit organizations are funded in instances in which the organization's project is an excellent fit with strategies and the Foundation feels the organization is best suited to do the work. The goal of the funding is to explore; to look into the future and put health first as we design for changes in how we live, learn, work and play; to wade into uncharted territory in order to better understand what new trends, opportunities, and breakthrough ideas can enable everyone in the United States to live the healthiest life possible.
- Bloomberg Philanthropies takes the approach of bringing together people, ideas and resources from across sectors toward a common purpose and amplifying their impact. Bloomberg supports public health in the areas of, for example: maternal and reproductive health; and data for health. They focus on five key areas for creating lasting change: public health, environment, education, government innovation, and arts and culture. Bloomberg Philanthropies helps to turn proven ideas into widespread solutions, and tailors them as needed to scale up their impact. Grant proposals are by invitation only, however, Bloomberg Philanthropies is always open to new ideas from new sources via their contact form.
- The Belmont Forum is launching a series of calls for collaborative research on Climate, Environment and Health. While not an explicit area of the CRA at this stage, if there were interest among funders (European Union, United States' National Science Foundation, United Kingdom, others), it could be easily incorporated into future iterations of this research call.
- The International Red Cross may have interest and capabilities in this area.
- There may be interest in this topic from other United States' agencies.

F. Cross-cutting Issues: Regional Foci, Vulnerable Populations, Data/Access – Especially Concerning Health, Capacity Building, and Training

Primary goal: Increase the awareness of using EOs with other data to prevent and respond to health-related problems.

Outcomes:

- Recognize the need for geospatial reference layers (settlement names & locations, key points of interest, validated administrative boundaries) and bottom-up population estimates (based on satellite imagery and microcensus data).
- Provide context to support emergency response/humanitarian disasters, specialized/programmatic data sets, and government planning and infrastructure.
- Health care infrastructure suitable for emergency response, capacities and available equipment, relevant medicine supplies and vaccines.
- Promote formal partnerships with host governments and affected communities, which includes data governance and access policies, and the capacity-building necessary to use, manage and sustain the country geodatabase.
- Examine the spatial pattern and urban determinants of health (e.g., mosquito-borne diseases, heat, water supply and quality, air quality, vulnerable human populations).
- Refine mosquito-borne disease mapping for vulnerable human populations.
- Promote formal partnerships with host governments, which includes data governance and access policies, and capacity-building necessary to use, manage, and sustain the country geodatabase.

Identification of critical EO and prediction requirements for health (e.g., What data and surveillance systems and tools are you currently using?)

- Census data, cases reports, human cases databases such as hospitalization and morbidity
- The annual evolution of these data (in same cases seasonal evolution might be needed)

What data and surveillance systems and tools do you need to be able to measure risk better for future projects?

- Need for geographical location for human cases (restricted for privacy). In case of no census data, then use population density estimates (i.e,. Ebola in west Africa). For vector-borne diseases, such as mosquito-borne disease, fine resolution EO data (i.e., Rapid Eye) are needed to target the risk and to provide info for prevention and control actions).
- Need to develop downscaling methods (modules and necessary numerical processing tool) to allocate to the pixel size a vulnerable population density. Need to integrated spatial component of human risk in public health surveillance systems.
- Need to ensure that the downscaling process should be developed, tested and verified not in emergencies but under normal conditions.
- Need dialogue between health practitioners/emergency responders and EO scientists, so that data requests are feasible and data provided is at the geographic and temporal scale needed for action.

G. Integrating EO-based Population and Data Disaggregation Techniques in One Health Tools and Projects

Context

Infectious zoonotic diseases exist as a human-environment-animal continuum given the close and complex relationships between the environment, ecosystems, and the etiological agents of disease in human and animal populations. The transdisciplinary integration of these aspects, and their respective sciences and responsible agencies involved in their management, is known as One Health (Cunningham et al. 2017). Infectious diseases emerge and re-emerge under the influence of key drivers, which include the environmental, climatic, demographic, socio-economic and human behavioral changes that are challenging public health locally and globally via their impact on infectious diseases (Jones et al. 2008). By understanding how the key drivers affect disease occurrence allows us to predict when, how, and where disease will emerge as well as identify the populations at risk, and those most vulnerable (Altizer et al. 2013).

<u>Challenges and Needs</u>

One challenge that public health is facing is the access to timely, accurate and authoritative data to undertake analysis and support effective evidence-based decision-making pertaining to public health matters. There is a need to develop appropriate tools and data to enable the health community to address public health needs related to EO products and technologies as well as spatial, analytical and timely solutions to make the technology more reachable (i.e., easy/ready to use, implement and operationalize) by the public health community, especially for epidemiological analysis, risk modelling, surveillance, investigation and emergency management. To facilitate the development and implementation of EO science and technology in the health sector, organizational and technical interoperability would have to be enabled.

<u>Primary Goals</u>: Identification of authoritative reference data, missing information and assessment of capacity of GEO to provide human and animal data and methods to answer the need for the health community

1) Valuable current EO data, derived products, methods and models that could support One health system and tools for risk assessment, surveillance, emergency / outbreak management or any prevention or control action.
2) Valuable human and animal population census, surveillance or health data (e.g. occurrence, prevalence, incidence) for calibrating and validating the finding from EO derived products (e.g. risk maps, pop density map).
3) Identification of requirement for real-time (or near real time) data to support decision-making – this would help identify current gaps.
4) Identification of appropriate data standards that enable interoperability.
5) Missing, hard to collect, private, protected data or gaps in methods and models that limit the EO and public health community in their mandate.
6) GEO supporting dialogue between health stakeholders and EO stakeholders, to determine which data/data products are most "valuable" and which are actually feasible given current technologies
7) While EO data are well established in developing risk assessments and risk maps and as a key research tool in understanding risk, there are potentially critical applications in other aspects of public health that are under investigation and development. Identification of potential EO niche for health – e.g. surveillance systems, emergency preparedness and response.
    a. These include: i) increased need under emergency response conditions for intelligence on disease risk that may only be available using EO proxy data; and ii) capacity to assess the status of impacts, infrastructure and access that may be crucial to implementing public health measures. An example of the latter would be the capacity of EO data to reveal the accessibility of Ebola-affected villages, and selection of locations for mobile diagnostic laboratories.

<u>Outcomes</u>:

- Promote an open data policy and explore the various ways that EO data can be disseminated and integrated in decision tools.

- Provide authoritative reference data solution and limitation as well as technical, operational and organizational capacity and challenges.
- Provide EO solutions to produce risk maps of infectious and chronic diseases at different authoritative scale (e.g. local, regional, global).
- Propose EO data, geoanalytics and risk assessment methods to provide the basis for future characterization of transmission/exposure risks from different disease risks influenced by climate and environment associated to vulnerable populations.
- Provide to decision makers the potential for EO to support health practices: Infectious disease prevention and control; Emergency preparedness; Outbreak management; Intelligence synthesis for emerging issues/events; Chronic disease prevention and control; Risk assessment and environmental health; Social determinants of health and health promotion; Health surveillance and exposure surveillance; Knowledge-transfer and communication; Upstream research.

Identification of critical EO and prediction requirements for health (e.g., What data and surveillance systems and tools are you currently using?)

The Public Health Agency of Canada (PHAC) uses Geomatics analytical tools and Risk maps based on geospatial information on environmental conditions (particularly climate and habitat) for vector population persistence, assist public health in targeting areas and populations at risk with surveillance and prevention and control programs. To strengthen PHAC's response to emerging VBD threats, continued development, assessment, and implementation of innovative technologies, such as EO, are required to provide science-based information for public health decisions and actions.

The PHAC uses surveillance data for mosquito- and tick-borne diseases, such as Lyme disease and West Nile virus. The surveillance data are for ticks and mosquito active (field collected) and passive (e.g,. volunteers that make their dog or tick analyses in lab via the veterinarian) surveillance and also human case surveillance.

What data and surveillance systems and tools do you need to be able to measure risk better for future projects?

More intensive field survey. More data on the population vulnerability to infectious diseases. The data can be for physical, behavioral, educational, cultural or any socio-economics or demographics population vulnerability. More data on animal host distribution and animal cases.

References:

- Cunningham AA, Scoones I, Wood JLN. 2017. Introduction: One Health for a changing world: new perspectives from Africa. Phil. Trans. R. Soc. B 372, 20160162.
- Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, Daszak P. 2008. Global trends in emerging infectious diseases. Nature 451, 990-993.
- Altizer S, Ostfeld RS, Johnson PT, Kutz S, Harvell CD. 2013. Climate change and infectious diseases: from evidence to a predictive framework. Science 341, 514-519.
- Ogden NH, Lindsay LR, Schofield SW. (2015) Review of methods to prevent and manage tick bites for the purpose of reducing risk of Lyme disease. Canada Communicable Disease Report. 41, 146-153.