Earth Observations for Health (EO4Health) Initiative
2023-2025 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 serves 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 data 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 timely insight and feedback on future EO actions for health.
- Objective 5: Participate with other individuals, Group on Earth Observations (GEO) communities of practice, and institutions to leverage expertise that can produce an outcome greater than that achievable otherwise.

As a GEO Initiative, EO4Health helps 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. As an element of the GEO Health Community of Practice (CoP), EO4Health supported the GEO Health CoP in the development and elaboration of the CoP Work Plan. The CoP Work Plan aligns with the EO4Health objectives and includes work groups on five specific topics: 1) heat; 2) infectious diseases; 3) air quality, wildfires, and respiratory health; 4) food security and safety; and 5) health care infrastructure.

Previous work within the GEO Health CoP 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 IIS that sustain engagement between scientists and decision makers to provide useful EO data that protect public health and build community resilience. The GEO Health CoP also builds partnerships across public and

private sectors as well as encourages innovative and open approaches to gathering and providing useful risk assessment, monitoring, prediction, and forecasting information.

EO4Health leverages 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 sectors and geographic regions, including academic institutions, nongovernmental organizations, nonprofit organizations, private companies, and state, federal, and international governmental agencies. These networks were instrumental to foster knowledge exchange, share data tools and resources, and collaborate on ongoing research applications during the COVID-19 pandemic.

Over the next year, EO4Health will continue to promote interdisciplinary collaborations by expanding scientific connections and partnerships with the public health community across regional GEO activities and projects. Over the next three years, EO4Health will also support the related GEO activities and tasks that aim to strengthen the use of EO data for health decision-making.

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1. Purpose

The use of 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 and offer a sustainable framework for investment in research development and capacity building in environmental 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 several 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. The technologies used at the intersection of big data and artificial intelligence in the environmental health sciences, combined with advances in bioinformatics, analytics, and modeling, have the potential to advance scientific discovery and influence population health. 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 Global Strategy on Health, Environment and Climate Change for 2019-2023 highlights six objectives: 1) focusing on primary prevention and health promotion to mitigate disease risks; 2) improving cross-sectoral action; 3) strengthening health sector leadership, governance, and coordination; 4) building support for governance and political and social support; 5) enhancing evidence-based information and communication approaches; and 6) monitoring progress toward the SDGs.[5] Notably, this WHO strategy builds upon the WHO Work Plan on Climate Change and Health for 2014-2019, which aimed to strengthen scientific partnerships to support climate and health initiatives, increase awareness on climate-health links, encourage the generation of evidence-based scientific information, and offer technical support on related topics.[6] It also adds to the preceding work plan of 2009-2014, which emphasized the need for innovative tools to improve systematic data collection of country-specific information and monitor progress of established objectives. Over the next decade, these innovative data and tools include the use of space-based geospatial information in health applications and technological advancements, which inform decision-making activities and strengthen scientific communication.[7,8]

With pressing environmental health challenges, many countries, international organizations, and private entities are actively expanding investments in research development and capacity building in efforts to develop policies for sustainable actions that strengthen environmental security. 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 in environmental health sciences.

1.2 Mission

The mission of the Earth Observations for Health (EO4Health) Initiative is to foster the development of 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 data 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 timely insight and feedback on future EO actions for health.
- Objective 5: Participate with other individuals, GEO communities of practice, and institutions to leverage expertise that can produce an outcome greater than that achievable otherwise.

1.4 Description of Planned Activities

The EO4Health Initiative’s Implementation 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 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. Planned activities will focus on specific tasks that support the health-related SDGs of targets 3.3, 3.9, and 3.d. 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.

As an element of the GEO Health Community of Practice (CoP), EO4Health has supported the GEO Health CoP in the development and elaboration of the CoP Work Plan. Work 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. Work groups will be aligned with the EO4Health objectives and focus on five specific topics: 1) heat; 2) infectious diseases; 3) air quality, wildfires, and respiratory health; 4) food security and safety; and 5) health care infrastructure. Cross-cutting synergies among work groups will be instrumental in identifying critical EO needs and science gaps between coinciding environmental health challenges. The One Health framework, which promotes transdisciplinary collaborations to better understand the interlinking processes of human, animal, and environmental health, will be an integrated theme across all activities.[9]

These activities will support ongoing GEO efforts and the GEO Work Programme tasks, including:

- <u>GEO Health CoP</u>: The GEO Health CoP work groups focus on five topics: 1) heat; 2) infectious diseases; 3) air quality, wildfires, and respiratory health; 4) food security and safety; and 5) health care infrastructure. These work groups promote shared data, tools, and other resources that facilitate collaborative research applications, which have been especially valuable during the COVID-19 pandemic. These multidisciplinary scientific areas lend themselves to cross-collaborations and synergies among various GEO groups.

- <u>GEO AquaWatch</u>: 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 work group participants.

- <u>GEO Blue Planet</u>: GEO Blue Planet has formed a work group on early warning systems for water-associated diseases, where the GEO Health CoP has served as an active partner. Potential GEO collaborations include synergistic efforts to examine environmental risks associated with water quality along coastal areas.

- <u>Regional GEOs</u>: The GEO Health CoP has strengthened connections with the Americas Group on Earth Observations (AmeriGEO), as health was adopted as a fifth thematic community at the AmeriGEO Week 2020. The GEO Health CoP organized Special Edition Webinars for AmeriGEO in 2021 and the African Group on Earth Observations (AfriGEO) in 2022. Potential GEO collaborations include developing Special Edition Webinars to bridge networks of Earth and health science communities within Asia-Oceania Group on Earth Observations (AOGEO) and European Group on Earth Observations (EuroGEO).

1.5 Participants and Contributors

EO4Heath participants currently include representatives across the public and private sector and geographic regions, including academic institutions, nongovernmental organizations, nonprofit organizations, private companies, and state, federal, and international governmental agencies. Participants attend and contribute to the agenda of community telecons, virtual and in-person conference meetings, and work group tasks and activities.

The EO4Health Initiative will 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), GEO Human Planet Initiative, and Global Water Sustainability (GEOGLOWS), as well as regional GEOs, such as AfriGEO, AmeriGEO, AOGEO, and EuroGEO.

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 community telecons, virtual and in-person scientific conferences, and social media technology. Future opportunities for cross-collaboration between the GEO Health CoP, GEO AquaWatch, and GEO Blue Planet have been identified to explore pathogen tracking with applications to sustainable fisheries and food safety among subsistence fishers. Additional synergies between the GEO Health CoP and regional GEOs have been explored to support potential collaborations in heat, infectious diseases, air quality, food security and safety, and health care infrastructure topics.

2. Background and Previous Achievements

By building upon the framework of the EO4Health Initiative (Implementation Plan 2020-2022)[10], the EO4Health Initiative (Implementation Plan 2023-2025) 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.

2.1 Previous Achievements with GEO Health Community of Practice

The EO4Health Initiative has supported the robust work groups of the GEO Health CoP in the development and elaboration of the CoP Implementation 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. Work groups will be aligned with the EO4Health objectives and focus on five specific topics – 1) heat; 2) infectious diseases; 3) air quality, wildfires, and respiratory health; 4) food security and safety; and 5) health care infrastructure – and promote shared data, tools, and other resources to facilitate research collaborations.

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 builds partnerships across Earth and health communities and public and private sectors, which aim to stimulate innovative and open approaches to gather and provide useful risk assessment, monitoring, prediction, and forecasting information.

In order to promote EO for health in scientific exchanges, the GEO Health CoP has coordinated community telecons and virtual 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, with a community listserv, where upcoming activities, news, and other updates, calls for scientific publications, and funding opportunities are shared with CoP members and the global community.[11]

Notably, the GEO Health CoP was strategically placed at the start of the COVID-19 pandemic to offer a platform for GEO Health CoP members worldwide to share research applications and related activities that use Earth observations to advance knowledge on COVID-19 transmission. A series of weekly teleconferences on *EO and COVID-19: A Virtual Round the Room Update* was coordinated to present preliminary scientific findings and encourage research collaborations that explore environmental factors that could possibly influence COVID-19 transmission. These teleconferences also offered opportunities for GEO Health CoP members to participate in global scientific events, such as the World Meteorological Organization (WMO)/WHO Workshop on *Climatological, Meteorological, and Environmental Factors in the COVID-19 Pandemic* (August 2020), the First Report of the WMO COVID-19 Task Team: *Review on Meteorological and Air Quality Factors Affecting the COVID-19 Pandemic* (March 2021), and WMO COVID-19 Task Team Roundtables (June and September 2021). These efforts were noted in the GEO Highlights Report 2022 (Chapter 1: Community's Response to COVID-19).

The EO4Health Initiative was invited to coordinate a special session (Earth Observations for COVID-19 Response and Recovery) session of the GEO Virtual Symposium 2020, which offered resources and discuss priorities and challenges across geographic regions during the COVID-19 pandemic. The team was also encouraged to organize the Building Sustainable

Partnerships for Health Decision-Making and One Health Collaborations session at the GEO Virtual Symposium 2021, which shared three examples of sustainable cross-cutting collaborations to share knowledge on EO data and tools and support countries in their health decision-making and initiatives to achieve SDG targets.

As health was adopted as a fifth AmeriGEO thematic community at AmeriGEO Week 2020, the EO4Health Initiative was invited to participate in monthly AmeriGEO teleconferences. The team was encouraged to present a scientific panel and poster session on Health at the AmeriGEO Week 2021, where panelists highlighted the use of Earth observation data to examine the environmental risks of climate change, extreme temperatures, dust, and vector-borne disease on community health decision-making. The session also supported the Belmont Forum's Collaborative Research Actions on Climate, Environment, and Health in the Americas Workshop, which aimed to identify synergies for the development of research networks that address national priorities related to climate, environment, and health.

In efforts to expand collaborations with regional GEOs, the GEO Health CoP organized *Special Edition Webinars* for AmeriGEO in 2021 and AfriGEO in 2022, which offered GEO Health CoP member flash talks, followed by an interactive group discussion, to facilitate knowledge sharing and networking across disciplines, sectors, and geographic regions. Potential GEO collaborations include developing *Special Edition Webinars* to bridge networks of Earth and health science communities within AOGEO and EuroGEO.

2.2 Previous Achievements with Diverse Stakeholders

Over the past two years, the EO4Health Initiative tasks have incorporated capacity building for end-user communities, participation in specific global collaborations, dissemination of project findings to diverse stakeholders, and support for stakeholder engagement in the use of EO for health. These tasks have included four main components:

Capacity Building. The EO4Health Initiative 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.

Specific Global Collaborations. The team collaborated with several specific institutions to prepare content for master courses, workshop proceedings, and scientific publications. First, the team worked with Environmental Systems Research Institute (ESRI) in India to complete the Global Heat Health Information Network (GHHIN). They also helped develop content for GHHIN Masterclasses on heat-health topics, including understanding urban heat islands and developing effective heat health action plans. Second, the team contributed to global scientific events, such as the WMO/WHO Workshop on *Climatological, Meteorological, and Environmental Factors in the COVID-19 Pandemic* (August 2020), the First Report of the WMO COVID-19 Task Team: *Review on Meteorological and Air Quality Factors Affecting the COVID-19 Pandemic* (March 2021), and WMO COVID-19 Task Team Roundtables (June and September 2021). Finally, the team supported the Belmont Forum's Collaborative Research

Actions on Climate, Environment, and Health in the Americas Workshop, following AmeriGEO Week 2021, which identified synergies for the development of research networks that address priorities related to climate, environment, and health.

Funded Projects. The EO4Health Initiative has supported the GEO Work Programme through four NASA-funded EO4HEALTH projects (2017-2022) and the Dengue forecasting MOdel Satellite-based System (D-MOSS). Several projects were in collaboration with AfriGEO and AmeriGEO, demonstrated sustainable partnerships for continued work on COVID-19 (**Figure 1**), and were presented by principal investigators in scientific conferences. Social media technology (e.g. Twitter, GEO Health CoP website) were used to disseminate scientific project findings and other global activities to diverse stakeholders. Some reports included 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).

Figure 1. EO4Health project on hydroclimatic factors and the COVID-19 pandemic. Credits: NASA

Support for Stakeholder Engagement. 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 was shared within the global community. Synergistically with other GEO initiatives, EO4Health activities aim to increase the number and diversity of disciplines (e.g. non-Earth science disciplines) through directly connections with end-user communities of EO data.

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. These efforts 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.

The EO4Health Initiative will continue to support the GEO Work Programme initiatives, including GEO AquaWatch (e.g. information sharing and access to water quality information), GEO Blue Planet (e.g. water-associated diseases), and regional GEOs (e.g. potential collaborations on work groups). They will 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, EO4Health supports five GEO Health CoP work groups, which were developed to facilitate the development and implementation of EO science and technology in the health sector across diverse environmental health topics. There are no specific timelines associated with these work groups at this time.

3.1 Work Group Activities

Work Group 1: Heat: Predict and Prevent Heat-related Health Risks across Time Scales

- Goal: Work Group 1 will continue 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.
- Activities: Work Group 1 hosts one-hour calls every two months, which serve as a platform for members to share research related outcomes, facility dialogue, and develop collaboration across the work group. Members also regularly present to the full GEO Health CoP, including GEO Week 2021 and AmeriGEO Week, and share potential funding sources to create sustainable and dedicated funding source to accomplish Work Group 1 outcomes.

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

- Goal: Work 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 a generalization framework for incorporating climatic and environmental data for enhancing predictive and decision-making mapping capacity to serve as the EO backbone for water- air- and vector-borne diseases; and 2) develop platform for the monitoring and prediction of emerging pathogens and toxins risk in marine and coastal environments coupled with critical EO-derived coastal and inland water quality parameters.
- Activities: Work Group 2 aims to establish a robust database on existing literature of EO for the prediction of environmentally-sensitive diseases knowledge base in literature. A dedicated website was prepared in 2022, where members will contribute to data entry, which will result in an illustrative map.

Work Group 3: Air Quality, Wildfires, Respiratory Health

- Goal: Work Group 3 aims to collectively advance the science of modeling satellite and sensor measurement data for monitoring, forecasting, and assessment of air quality, wildfire-related pollutants, and aeroallergens to quantify the levels of exposure associated with health risk for various population groups and the public.
- Activities: Work Group 3 aims to address the implications of changes in heat, wildfires, and resultant wildfire smoke emissions on air quality and human health implications through quarterly telecons. They meet quarterly and plan to develop a satellite data user guide specifically designed for the health and health IT community to implement solutions that deliver environmental health awareness for wildfire smoke incidents. They plan to develop a use case for tracking wildfire smoke emissions to show community health impact and inform local decision-making.

Work Group 4: Food Security and Safety

- Goal: Work Group 4 aims to strengthen EO applications to address food- and water-borne diseases that undermine health and food safety and security. They aim to better understand the needs of the decision-makers, the available tools, and the current gaps that exist in meeting the needs of the decision-makers through three questions: 1) How are EO being integrated with food systems data to provide actionable information on food security in regions with extreme food insecurity? 2) What is the impact of increasing heat on agricultural and ranching production – heat impacts on crops and grasslands, animals, and workers – in the western United States? 3) What are the impacts of algae blooms and toxins on water quality, shellfish, and aquaculture on the eastern coast of the United States? Work Group 4 will develop case studies to highlight examples of ongoing work and better understand the interrelated factors and complexities.
- Activities: Work Group 4 has developed a virtual document, where members can update information related to tasks. They meet every three months and discuss ongoing tasks to identify and build potential case studies.

Work Group 5: Health Care Infrastructure

- Goal: Work 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.
- Activities: Work Group 5 intends to assess the vulnerability of local health care facilities to local environmental stressors (e.g. flooding, coastal storm surges and winds, wildfires, threats to water supplies). They plan to examine associations of the local health care facilities to environmentally-induced diseases (e.g. severe heat waves, wildfire smoke events).

These five work 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 BON; GEO Global Agricultural Monitoring, GEOGLAM; GEO System for Mercury, GOS4M), initiatives (e.g. AfriGEO; AmeriGEO; AOGEO; EuroGEO; GEO AquaWatch; GEO 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

Vector-borne Diseases

- Dengue Model forecasting Satellite-based System (D-MOSS) (Gina Tsarouchi, Project Manager): Developed by a consortium led by HR Wallingford and sponsored by the United Kingdom (UK) Space Agency's International Partnership Programme, D-MOSS is the first fully integrated dengue fever forecasting system incorporating Earth observations and seasonal climate forecasts to issue warnings on a routine basis. D-MOSS integrates multiple stressors such as water availability, land-cover, precipitation, and temperature with data on past dengue fever incidents. This information is used to develop statistical models of disease incidence, which can then be used to forecast dengue outbreaks based on seasonal weather and hydrological forecasts as well as other factors. D-MOSS takes the form of a web-based platform. The system's architecture is based on open and non-proprietary software, where possible, and on flexible deployment into platforms including cloud-based virtual storage and application processing. D-MOSS has been implemented in Vietnam and is being expanded to Cambodia, Laos, Malaysia, Philippines, Sri Lanka, and Thailand. This suite of innovative tools will allow beneficiaries to issue alerts for dengue fever up to eight months in advance (with a view to develop the same for Zika virus) and provide assessments of vector-borne disease risk under future climate and land use change scenarios. It will allow local communities to mobilize and eliminate mosquito-breeding sites, thus reducing dengue incidence. (Funding: HR Wallingford)
- An Early Warning System for Vector-borne Disease Risk in the Amazon (William Pan, Duke University): In the Amazonian region of South America, the countries of Colombia, Peru, Ecuador, and Venezuela have experienced a resurgence in malaria, attributed to challenges like climate change and the expansion of mosquito habitats. To inform malaria control policies, the team developed a Malaria Early Warning System for Peru, which is capable of forecasting malaria outbreaks up to 12 weeks in advance (90% sensitivity). His team integrated multi-layered data from NASA's Land Data Assimilation System (LDAS), human population density, and weekly malaria surveillance to forecast both the incidence of malaria and probabilities of an outbreak (as defined by the local Ministries of Health). The team has developed strong government and academic partnerships in Peru (Peruvian Centers for Disease Control; Climate and Infectious Disease Laboratory at the Universidad Peruana Cayetano Heredia) and Ecuador (Ecuadorian Ministry of Health; University of San Francisco de Quito) to train and implement the system locally. (Funding: NASA ROSES 2013)

- Myanmar Malaria Early Warning System (Tatiana Loboda, University of Maryland, College Park): Myanmar is one of the five countries with documented cases of emergence of artemisinin resistance. This project developed a robust satellite data driven early warning system (Myanmar Malaria Early Warning System, MMEWS) that enables spatially-explicit monitoring and forecasting of potential surges in malaria burden in Myanmar. This approach quantified malaria outbreak potential using an IPCC-defined risk-assessment framework which included hazard, exposure, and vulnerability components. Data fusion from moderate (Landsat) and coarse (MODIS) resolution optical sensors supported the 8-day dynamic spatially explicit (resolved to village level) assessment of malaria burden potential. With a team of experts in satellite remote sensing, geospatial modeling, and malariology, the project offered support for medical intervention and other decision-making activities in the Yangon office of the Institute for Global Health and regional partners and stakeholders. Unfortunately, continued political instability in Myanmar has paused efforts to bring this system to full operational use in-country. (Funding: NASA ROSES 2017, Element A.37)
- A Geospatial Surveillance and Response System Resource for Vector-borne Disease in the Americas (John Malone, Louisiana State University and A&M College): Visceral leishmaniasis (*Lutzomyia longipalpis*) and *Aedes aegypti* borne arboviruses (dengue, zika, chikungunya) have potential for epizootic spread from Latin America and the Caribbean and establishment in North America. This project developed and implemented a geospatial surveillance and response system data resource for vector-borne diseases in the Americas using NASA satellite and public health surveillance data, geographic information systems, and ecological niche modeling. It characterized the environmental suitability and potential for spread of selected endemic and epizootic vector-borne diseases in the Americas, with an initial focus on visceral leishmaniasis in Brazil. This project has offered a geospatial health resource data portal with training courses for researchers interested in mapping and modeling other vector-borne diseases. (Funding: NASA ROSES 2017, Element A.37)
- Machine Learning, Climate Variability and Disease Dynamics (MEDINA) (Assaf Anyamba, NASA Goddard Space Flight Center): Vector-borne and zoonotic pathogens comprise at least two-thirds of top infectious disease threats to Department of Defense personnel and global public health, and account for more than 17% of all infections with more than 700,000 deaths per year. This project will develop and enhance risk mapping and forecasting of a suite of vector-borne disease models driven by extreme weather/climate conditions (i.e., dengue, Rift Valley fever, Zika, hantavirus) through prototype machine learning methods that integrate disparate climate, model, environmental, and disease outbreak data to deliver timely disease risk maps in a unified platform called MEDINA. (Funding: NASA ROSES 2021, Pending)
- Getting to Zero: Satellite Informed System to Support Elimination of Malaria in the Americas (SISTEMA) (William Pan, Duke University): Progress toward malaria elimination has stalled due to rapidly changing environmental conditions, increasing human population and mobility, social inequalities, and pathogen and mosquito adaptation. This project aims to develop real-time, satellite-informed tools to perform early and enhanced detection of novel malaria cases that improve the timing and spatial deployment of malaria interventions and speed progress toward malaria elimination. This system will be tested in Panama and Honduras, leveraging strong local presence and

government collaborations of Clinton Health Access Initiative (CHAI). (Funding: NASA ROSES 2021, Pending)

Water-related Pathogens

- Predictive Assessment of Transmission Conditions of Cholera in the Environment and Human Population using Earth Observations (Antarpreet Jutla, University of Florida**)**: Cholera is an acute diarrheal infection, caused by the ingestion of food or water contaminated with *Vibrio cholerae*. It remains a significant global health risk, where 40-80 million people are living in cholera hotspots in Africa. The real burden of cholera, which is underreported between 1.4 and 4 million cases, hinders the ability to predict high-risk areas of cholera outbreaks in Africa. This team integrated satellite data (MODIS, GPM, MERRA-2, ORNL LandScan) and validated a predictive model (Regional Cholera Prediction Modeling System) to produce weekly time steps for the epidemic and endemic models of cholera for Africa (Mozambique, Algeria, Zimbabwe, South Sudan, Sudan) and work with international agencies to inform cholera risk reduction in Yemen and other African nations. It developed a comprehensive regional specific capacity building plan to engage end-users to incorporate this information into decision-making and facilitate the creation and implementation of appropriate intervention strategies. (Funding: NASA ROSES 2017, Element A.37)
- Assimilation of Earth Observations to Improve and Enhance Global Predictive Ability of Forecasting Risk of Cholera Outbreaks (Antarpreet Jutla, University of Florida): Cholera, a diarrheal disease caused by drinking contaminated water containing bacterium *Vibrio cholerae*, remains a global threat to public health. This project aims to enhance the predictive ability of the cholera risk model through integration of the transmission component with the trigger component. It also aims to develop EO-based data architecture for effective dissemination and communication of cholera risks as well as an Anticipatory Decision-making toolkit for the deployment of cholera modeling systems on global scales. Deliverables include one of the first EO-based apps for predicting cholera, a web hub to monitor the risk of trigger and transmission, and an anticipatory decision-making framework for cholera on a global scale. (Funding: NASA ROSES 2021, Pending)

Air Quality

- Supporting Local Government Public Health and Air Quality Decision-Making with a Sub-City Scale Air Quality Forecasting System from Data Fusion of Models, Satellite, In Situ Measurements, and Low-Cost Sensors (Katherine Emma Knowland, NASA Goddard Space Flight Center): This project aims to address the needs of three end-user groups for sub-city scale air quality estimates and forecasts: 1) assess the impacts of new regional rail and bus rapid transit policies on spatial and temporal air quality distributions (Dakar, Senegal); 2) provide air quality forecasts across the city with early warnings to city hospitals to prepare for poor local air quality events (Rio de Janeiro, Brazil); 3) guide state, local, and tribal air quality managers on how to best incorporate data from low-cost sensors into their air quality management decision-making (United States). This project will expand the capabilities of this tool using new methods developed by the NASA GMAO which will give it the capability of providing sub-city scale resolution and hourly frequency estimates and forecasts of three key air quality indicators ($PM_{2.5}$, NO_2, O_3). (Funding: NASA ROSES 2021, Pending)

- Enhancing Air Quality Decision-Making Activity in Indian Megacities through Assimilation of NASA Earth Observations and Development of a Decision Support System (Rajesh Kumar, National Center for Atmospheric Research): An operational air quality early warning system for Delhi was developed, in collaboration with the Indian Institute of Tropical Meteorology, the Indian Meteorological Department, and the National Center for Atmospheric Research, which has provided 72-hour air quality forecasts daily since October 2018. The system, which assimilates MODIS aerosol optical depth (AOD) retrievals, has been shown to improve the accuracy of fine particulate matter ($PM_{2.5}$) forecasts in Delhi by 70-86% during the crop-residue burning season. This project aims to develop a machine learning based decision support system that will help decision-makers to assess the relative importance of controlling target emission sources predefined in Grades Response Action Plan and implement the most effective control measures. The team will also develop high-resolution (400 m x 400 m) AQEWS for five additional Indian megacities namely Ahmedabad, Bengaluru, Pune, Indore and Bhubaneswar. (Funding: NASA ROSES 2021, Pending)

Environmental Health Topics

- Environmental Determinants of Enteric Infectious Disease (Ben Zaitchik, Johns Hopkins University): Gastrointestinal diseases contribute to childhood undernutrition, causing more than 50% of global deaths in children aged < 5 years. A previous eight-site cohort study, Foundations of the NIH's Malnutrition and Enteric Disease Study (MAL-ED), which generated a high-quality data set (cognitive abilities, gut function, immunological response), reported that gastrointestinal diseases are sensitive to environmental conditions. This team integrated satellite data (GPM, SMAP, LDAS) to examine hydrometerological factors (temperature, soil moisture, precipitation) to better understand global rates of gastrointestinal illnesses (like rotavirus). The team developed a database of relevant climate, hydrology, ecology, and human activity at global gastrointestinal disease study sites in Iquitos (Peru), Fortaleza (Brazil), Naushero Feroze (Pakistan), Vellore (India), Bhaktapu (Nepal), Dhaka (Bangladesh), Limpopo (South Africa), and Haydom (Tanzania). (Funding: NASA ROSES 2017, Element A.37)
- Environmental Determinants and COVID-19 (Ben Zaitchik, Johns Hopkins University): This project addressed the environmental, economic, and societal impacts of the COVID-19 pandemic. The team used GPM, SMAP, LDAS, and MERRA-2 data to examine climatic and hydrometeorological factors in temporal and spatial variability that may influence COVID-19 transmission. They integrated the database of the original project (Environmental Determinants of Enteric Infectious Disease) with COVID-19 information from the Johns Hopkins Coronavirus Resource Center to investigate potential environmental factors that may influence COVID-19 transmission. His team refined the COVID-19 case record database, which assigned data to a consistent geographical hierarchy aligned with hydrometeorological variables, and completed the COVID-19 risk analyses for Brazil, the United States, and selected South and Central American countries. (Funding: NASA Rapid Response and Novel Research in Earth Science ROSES 2020)

- Neighborhood-Scale Extreme Humid Heat Health Impact (Peter Kalmus, Jet Propulsion Laboratory): In coming decades, deadly heat will intensify but will be unevenly distributed in space and wealth, disproportionately affecting the tropics and vulnerable urban populations with limited or no access to reliable air conditioning. Using global climate models, high-resolution remote sensing data sets, and health data, this project will create projections of humid heat to 2100 and connect them to human health impacts. This work will target the world's major urban centers and provide humid heat impact projections at the neighborhood scale (375 meters), capable of resolving urban heat islands and providing precise spatial guidance to enhance decision-making activities around urban climate planning for mitigation and adaptation such as cooling centers, air conditioning capacity, cool roofs and surfaces, urban forests, and parametric insurance. (Funding: NASA ROSES 2021, Pending)

3.3 Additional EO4Health Activities

Urban Heat Island: Members of the GEO Health CoP participated in the community-led summer campaigns, supported by NOAA's National Integrated Heat Information System and partners, to map the hottest parts of cities in 11 states across the United States (NOAA and Communities to Map Heat Inequities in 11 States). In 2021, selected communities included Albuquerque, New Mexico; Atlanta; New York City; Charleston, South Carolina; Kansas City, Missouri; Raleigh & Durham, North Carolina; San Diego; San Francisco; and parts of New Jersey, Indiana, Massachusetts, and Virginia. Ongoing work will focus on future community-led summer campaigns to map selected cities in the United States.

WMO COVID-19 Task Team: Members of the GEO Health CoP have contributed to global scientific events, such as the WMO/WHO Workshop on *Climatological, Meteorological, and Environmental Factors in the COVID-19 Pandemic* (August 2020), the First Report of the WMO COVID-19 Task Team: *Review on Meteorological and Air Quality Factors Affecting the COVID-19 Pandemic* (March 2021), and WMO COVID-19 Task Team Virtual Roundtables (June and September 2021). Ongoing work will focus on the potential for meteorological factors to inform decision-making activities related to COVID-19 and future disease outbreaks.

Belmont Forum: The team supported the Belmont Forum's Collaborative Research Actions on Climate, Environment, and Health in the Americas Workshop, following AmeriGEO Week 2021. This workshop identified synergies for the development of research networks that address priorities related to climate, environment, and health and will guide the upcoming Collaborative Research Action (CRA) on Climate, Environment and Health (CEH2) in early 2022. Ongoing work will focus on regional training workshops, in collaboration with the Inter-American Institute of Global Change Research (IAI), in 2022.

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

The EO4Health Initiative participants currently include representatives across the public and private sectors and geographic regions, 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
- GEO AquaWatch
- GEO Blue Planet
- GEO BON
- GEO Human Planet Initiative
- GEOGLOWS
- AfriGEO
- AmeriGEO
- AOGEO
- EuroGEO

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:

- Individual capacity building: The EO4Health Initiative 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 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: The EO4Health Initiative 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: The EO4Health Initiative will continue to seek collaborations that promote the use of EO data and technology to diverse end-user communities. Through community telecons and annual virtual and in-person meetings, the GEO Health CoP work 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, the EO4Health Initiative will continue to expand connections with end-user communities of EO data who represent other sectors, agencies, and countries, including commercial end-user communities of EO data. EO4Health intends to establish 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 offers integral links to strengthen the framework of the EO4Health Initiative (**Figure 2**). These components include:

EO4Health Co-Chair Leadership: The guidance of the GEO Secretariat staff is beneficial as it facilitates integrated functions in activities as well as supports connections to other GEO flagships, initiatives, and regional networks. The 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; WMO) will provide scientific and technical expertise as well as facilitate an open dialogue for interdisciplinary collaborations using EO for health.

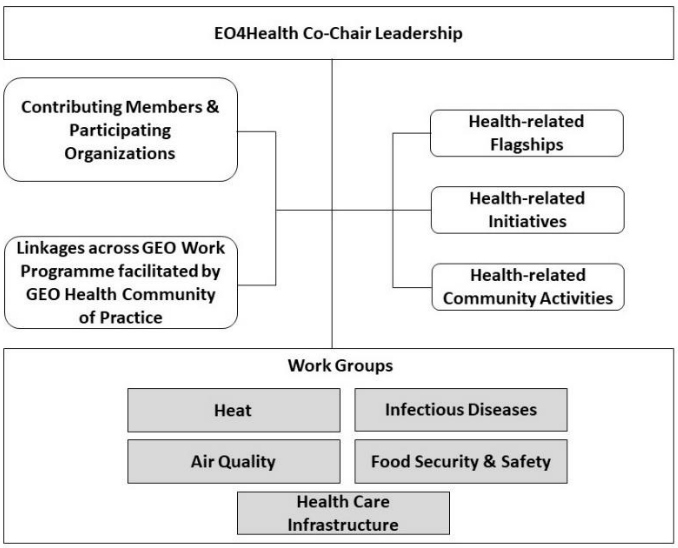
Linkages across GEO Work Programme: These linkages, facilitated by GEO Health CoP, will support the implementation and sustainability of the EO4Health framework, including mission, goals, objectives, and activities.

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. AfriGEO; AmeriGEO; AOGEO; EuroGEO; GEO AquaWatch; GEO 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.

Work Groups: EO4Health will leverage the five work 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 2. 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 previously supported four EO4Health projects (2017-2022), with financial contributions (US$2.4 million) from NASA, based in Washington, DC (USA). D-MOSS is supported through financial contributions of HR Wallingford (UK). Additional support through in-kind participation and contributions of other resources includes six organizations: 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). There is no formal Memorandum of Understanding (MoU) at this time.

EO4Health will seek additional resources to support the planned activities during the 2023-2025 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, European Space Agency (ESA)'s Copernicus system, and the tri-agency COVID-19 Earth Observing Dashboard by NASA, ESA, and Japan Aerospace Exploration Agency (JAXA). Additional examples are NASA ARSET online and in-person trainings on diverse environmental health topics, NASA 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 2023-2025 time period.

EO4Health will seek additional data and technology sources to support the planned activities during the 2023-2025 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.[12,13]. 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. With guidance by the GEO Secretariat staff, GEO members of the established five work groups can examine best practices associated with data sharing and management principles, which enhance the use of EO data for health decision-making. Over the next few years, EO4Health will continue to coordinate data, tools, and other resources produced by the initiative, to strengthen GEO efforts and activities.

Annex A – Acronyms and Abbreviations

AfriGEO	African Group on Earth Observations
AIDS	Acquired Immunodeficiency Syndrome
AmeriGEO	Americas Group on Earth Observations
AOGEO	Asia-Oceania Group on Earth Observations
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
EuroGEO	European Group on Earth Observations
GEO	Group on Earth Observations
GEO BON	Group on Earth Observations Biodiversity Observation Network
GEOGLAM	Group on Earth Observations Global Agricultural Monitoring
GEOGLOWS	Group on Earth Observations Global Water Sustainability
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
ICDDR,B	International Centre for Diarrhoeal Disease Research, Bangladesh
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
SANSA	South African National Space Agency
SDG	Sustainable Development Goals
SMAP	Soil Moisture Active Passive
UCAR	University Corporation for Atmospheric Research
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UNICEF	United Nations Children’s Fund
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. Geneva, Switzerland: GEO; 2015. https://earthobservations.org/documents/open_eo_data/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. What is the Sendai Framework for Disaster Risk Reduction? 2015. https://www.undrr.org/implementing-sendai-framework/what-sendai-framework

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

[5] World Health Organization. WHO global strategy on health, environment and climate change: the transformation needed to improve lives and wellbeing sustainably through healthy environments. Geneva, Switzerland: WHO; 2020. https://apps.who.int/iris/bitstream/handle/10665/331959/9789240000377-eng.pdf

[6] 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

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

[8] World Health Organization. Urgent health challenges for the next decade. 2020. https://www.who.int/news-room/photo-story/photo-story-detail/urgent-health-challenges-for-the-next-decade

[9] World Health Organization. Tripartite and UNEP support OHHLEP's definition of "One Health". 2021. https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health

[10] Group on Earth Observations. GEO 2020-2022 Work Programme: Earth Observations for Health (EO4Health). Geneva, Switzerland: GEO; 2020. https://www.earthobservations.org/documents/gwp20_22/EO4HEALTH.pdf

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

[12] 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

[13] 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. The Program promotes the use of Earth observations in air quality management and public health, particularly involving environmental health and infectious diseases.

Among his responsibilities, John is Co-Chair of the Group on Earth Observations (GEO) Health Community of Practice and the Earth Observations for Health (EO4Health) Initiative. He serves as the NASA Mission Applications Lead on the Tropospheric Emissions: Monitoring Pollution (TEMPO), Multi-Angle Imager for Aerosols (MAIA), and Atmosphere Observing System (AOS) satellite missions.

John has received several awards during his tenure at NASA including a NASA Aviation Safety and Security Program Award, three NASA Group Achievement Awards, a One NASA Award, a 2017 Team Excellence Award, and NASA's 2020 Exceptional Service Medal. In 2006, John was honored by his alma mater (the University of South Alabama) as an Exceptional Alumnus of the School of Meteorology.

John received his master’s degree in Meteorology from the University of Oklahoma and bachelor’s degree in Meteorology from the University of South Alabama.

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 – Work Group Membership

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

- Co-Chairs:
  - Ben Zaitchik, Johns Hopkins University (USA)
  - Cascade Tuholske, CIESIN/Columbia University (USA)
- Members (based on current mailing list):
  - 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 Skouloudis, Joint Research Centre (Italy)
  - Christian Braneon, NASA Goddard Institute for Space Studies (USA)
  - Paula Fievez, FrontierSI (Australia)
  - Natalie Thomas, NASA Goddard (USA)
  - Joy Shumake-Guillemot, WMO-WHO (Switzerland)
  - Ashish Sharma, University of Illinois Urbana-Champaign (USA)
  - Sushel Unninayar, NASA Goddard & KBR/Morgan State University (USA)
  - Tabassum Insaf, New York State Department of Public Health (USA)
  - Melissa MacDonald, Environment Canada (Canada)
  - Peter Kalmus, NASA/Jet Propulsion Laboratory (USA)
  - Justine Blanford, University of Twente (Netherlands)
  - Zackary Guido, University of Arizona (USA)
  - Kimberly McMahon - NOAA National Weather Service (USA)
  - Carolina Pereira Marghidan, University of Twente (Netherlands)
  - Shivam Gupta, Bonn Alliance for Sustainability Research (Germany)
  - Lewis Ziska, Columbia University (USA)
  - Xiaojiang Li, Temple University (USA)
  - Yuhan (Douglas) Rao, North Carolina State University (USA)
  - Mercy Julia Borbor Cordova, Escuela Superior Politécnica del Litoral (Ecuador)

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

- Chair:
  - Antarpreet Jutla, University of Florida (USA)
- Members:
  - Stéphanie Brazeau, Public Health Agency of Canada (Canada)
  - Josh Colston, University of Virginia (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)

Work Group 3 – Air Quality, Wildfires, Respiratory Health

- Co-Chairs:
    - Eric Klos, DailyBreath (USA)
    - Pawan Gupta (NASA Goddard/USRA) (USA)
- Members:
    - Paula Fievez, FrontierSI (Australia)
    - Harry Chow, Monash University (Australia)
    - Didier Davignon, Meteorological Service of Canada (Canada)
    - Yuddy Ramos, University of Montreal (Canada)
    - Celine Audette, Environment and Climate Change Canada (Canada)
    - Shivam Gupta, Bonn Alliance for Sustainability Research (Germany)
    - Andreas Skouloudis, Joint Research Centre (Italy)
    - Beatriz Cardenas, World Resources Institute (Mexico)
    - Olayinka Osuolale, Elizade University (Nigeria)
    - Michael Gebreslasie, University of KwaZulu-Natal (South Africa)
    - Brad Goodwin, CDC (USA)
    - Gary Foley, Environmental Protection Agency (retired) (USA)
    - Sushel Unninayar, NASA Goddard & KBR/Morgan State University (USA)
    - Jean Paul Vernier, NASA Langley (USA)
    - Falguni Patadia, NASA/Morgan State University (USA)
    - Ramon Martinez, Pan American Health Organization (USA)
    - Karin Troncoso Torrez, Pan American Health Organization (USA)
    - Juan Castillo, Pan American Health Organization (PAHO) (USA)
    - Tatiana Loboda, University of Maryland, College Park (USA)
    - Ana Prados, University of Maryland, Baltimore County (USA)
    - Antarpreet Jutla, University of Florida (USA)
    - Nathan Pavlovic, Sonoma Technology (USA)

Work Group 4 – Food Security and Safety

- Chair:
    - Dorian Janney, NASA Goddard/ADNET (USA)
- Members:
    - Antarpreet Jutla, University of Florida (USA)
    - Ben Zaitchik, John Hopkins University (USA)
    - Steven Rekant, USDA (USA)
    - Michael S. Gremillion, University of Alabama (USA)
    - Josh Glasser, U.S. Department of State (USA)
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Work Group 5 – Health Care Infrastructure

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Annex F – Work Plan for GEO Health CoP in support of EO4Health Initiative

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

Primary Goal: 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 integrated information systems 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 (2-year and 5-year): Building from these existing efforts, the GEO Health CoP aims to achieve several 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.

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?): 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 relevance to health interventions.

Anticipated Risks: The biggest challenge to achieving Work Group 1 outcomes is the lack of dedicated funding to support these efforts. While members have advanced individual efforts toward achieving these outcomes, at present, no funding supports collaboration across Work Group 1. Work Group 1 functions because members volunteer their limited time, and no one is currently funded to spearhead efforts to achieve the outcomes of Work Group 1.

Top Three Needs for Success (including data infrastructure):

1. Dedicated funding and personnel time.
2. Greater participation from stakeholders/researchers outside of North America and Europe.
3. Targeted task to engage work group members in a focused manner.

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 a generalization framework for incorporating climatic and environmental data for enhancing predictive and decision-making mapping capacity to serve as the EO backbone for water- air- and vector-borne diseases; and 2) develop platform for the monitoring and prediction of emerging pathogens and toxins risk in marine and coastal environments coupled with critical EO-derived coastal and inland water quality parameters.

Outcomes (2-year and 5-year):

- 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)

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?):

- 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.

Anticipated Risks: No risks are identified.

Top Three Needs for Success (including data infrastructure):

1. Members expressed concerns that the compilation of data and knowledge will require substantial time and therefore it may be worth to invest in a post-doctoral scientist who can work specifically towards this project objectives.
2. Inclusion of national, international, and selected stakeholders must be in dialogue with the team (or be part of the team). We make difference between stakeholders (who are

categorized as agencies capable to make decisions) and end users (who use the decision and data to improve health outcomes).

3. NASA data servers may be helpful to catalogue the database that we intend to develop, and it will need to be updated on a continuous basis.

C. Air Quality, Wildfires, and Respiratory Health

Primary Goal: Collectively advance the science of modeling satellite and sensor measurement data for monitoring, forecasting, and assessment of air quality, wildfire-related pollutants, and aeroallergens to quantify the levels of exposure associated with health risk for various population groups and the public at large.

Activities: Work Group 3 meetings were held in July and October 2021, where discussions surfaced the idea of developing a satellite data user guide specifically designed for the health and health IT community to implement solutions that deliver environmental health awareness for wildfire smoke events. The question guiding our work is: How can wildfire smoke data (visual or otherwise) be consumed by public health and the healthcare delivery system to support better patient health and better patient care response associated with wildfire smoke incidents. Our work efforts will: 1) assess how public health and health care delivery at local level can accommodate wildfire smoke information and alerts to notify public and be prepared for emergency action; and 2) inventory opportunities within health IT (EHRs, digital health) to integrate environmental awareness into health records of patients with specific health conditions and/or into patient engagement support via digital health solutions.

Near-Term Activities: We propose working to develop a project that would provide a Use Case for Tracking Wildfire Smoke Emissions to Show Community Health Impact and Inform Local Decision-Making. To proceed with this project, we will:

1) Identify among Small Work Group, interested volunteers for Use Case Project.
2) Identify a community with stakeholders representing public officials, county health department, and public, private health systems that would partner to consume wildfire smoke emission product.
3) Identify technologies, tools, mediums for communication of wildfire smoke risk to local communities.
4) Leverage project to develop a user guide specifically designed for the health and health IT community to implement solutions that deliver environmental health awareness of wildfire smoke events.

Outcomes (2-years and 5-years):

- Understand and address the implications of changes in heat, wildfires, and resultant wildfire smoke emissions on air quality and human health implications.
- 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).
- Produce air quality forecasts with wildland fire emissions.

- Monitor and track smoke plumes.
- Examine the finer granularity air quality data and modelling with COPD patient medication usage and physical movement through the neighborhood.
- 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 regional and national scales (including GP reports, health clinic reports) to assess health outcomes beyond acute responses reported through hospitalization and emergency room 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?):

<u>Satellite-based observations and datasets</u>:

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 wildfire smoke emissions and air quality.
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) Conduct medical studies that can link measured personal exposure levels to blood concentrations of the pollutants.
2) Examine the relationship between medicine consumption because of a fire event. Preliminary research has identified a relationship between medicine consumption and a heat event.
3) Examine the impacts of $PM_{2.5}$ from wildfire smoke on exposure levels, recognizing challenges to obtain health data to correlate health outcomes with wildfire $PM_{2.5}$.

Anticipated Risks:

1) The topics covered within Work Group 3 are broad ranging from air quality (pollution), aeroallergens. Each topic has significant challenges and could warrant an independent and singular focus. It could be perceived that focusing on wildfire smoke emissions is too narrow, but the idea is to focus on a unique exposure event to figure out the model for integrating available satellite-based data for wildfire smoke emissions into a decision-

making framework for public health, community health, healthcare delivery, and patient health and well-being. That model could similarly apply to integrating satellite-based data for other types of exposures, pollutants, and pollen.

2) We are too early in the research phase of measuring wildfire smoke emissions to create an adequate risk framework for distributing information that would drive health decision-making.

Top Three Needs for Success (including data infrastructure):

1) We need to determine how to calculate wildfire smoke emissions exceedance above normal air quality for an impacted community so that we can understand distinct impact of wildfire smoke apart from poor air quality on the health of a population.
2) We need to engage public health officials, community health workers, health care practitioners in a collaboration to determine the best way to communicate risk of wildfire smoke emission exceedance on the health and welfare of members of a community impacted by wildfire smoke.
3) We need to understand the technologies being used within health care and how to integrate satellite-based data into health IT and into the workflow of the public health official for emergency notification or the workflow of a healthcare practitioner in the community responding to patient concerns because of wildfire smoke exposure.

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.

Outcomes (2-year and 5-year): Work Group 4 will work collaboratively to answer the three key questions:

1) How are EO being integrated with food systems data to provide actionable information on food security in regions with extreme food insecurity?
2) What is the impact of increasing heat on agricultural and ranching production – heat impacts on crops and grasslands, animals, and workers – in the western United States?
3) What are the impacts of algae blooms and toxins on water quality, shellfish, and aquaculture on the eastern coast of the United States?

Work Group 4 aims to delve into finding answers and identifying related factors for each key question: 1) Who are the potential stakeholders? 2) Who are potential decision-makers? 3) What data are they relying on? 4) What is the current state of the research? 5) What are the gaps in the research? 6) What are the gaps in the available data? 7) What are the challenges that arise for marginalized populations? 8) What are additional resources that relate to this question?

Ongoing Work Group 4 tasks have identified the following research and data gaps.

Objective	Research gaps	Data gaps
1	• Monitoring and identifying smallholder crops. • Obtaining subseasonal to seasonal weather forecasts. • Water footprinting on commodities. • Approaching and working directly with farmers • Incorporating climate trends (EO) and climate change information in food-water-energy management at farm and state, national, and international levels. • Planning for climate change impacts on agricultural sustainability and mitigation measures at the regional to local (e.g., state or province) scale.	• Large gap in ground data from farmers to validate and calibrate models. • Gap in high-quality near-real-time meteorological data over food insecure regions, and weather-scale, sub-seasonal, and seasonal forecasts.
2	• Long term effects of conservation practices on crop yields. • Planning for climate change impacts on agricultural sustainability and mitigation measures at the regional to local (e.g., state or province) scale.	• Ground truthed data are expensive to collect and often difficult to obtain.

Existing Challenges: There are existing challenges that arise in data collection for marginalized populations, including:

- Since large farm owners may not allow heat stress information to be collected on their land, measurements are collected from nearby environments.
- Ground data can be hard to collect due to conflict and hard-to-reach areas.
- Some indigenous tribes have set up their own testing for biotoxins in shellfish like the Sitka Tribe of Alaska Environmental Research Laboratory (http://www.seator.org/lab), which provide more real-time data to their constituents and help prevent seafood biotoxin poisoning events.

E. Health Care Infrastructure

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 health care facilities (HCF) during seasonal loads and local population needs.
3. Develop methods to assess the adequacy of these infrastructures under regional extreme catastrophes raising demand for acute hospitalizations or during long-term chronic events as was recently the COVID-19 pandemic. 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 (2-years and 5-years): The infrastructure associated with HCF are already subject to registering and reporting by national ministries of health and the WHO as part of the Global Health Observatory (GHO). 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.

- 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 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?): Relevant EO could be utilized immediately from various GEO 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 wastewater 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.

An assessment of infrastructure of primary and secondary HCFs with capabilities can serve as a relevant instrument for health care applications (Example: Scholz S, Ngoli B, Flessa S. Rapid assessment of infrastructure of primary health care facilities - a relevant instrument for health care systems management. *BMC Health Serv Res*. 2015;15:183).

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). This could be advanced from EO (from multi EO satellites, United States, European Union, Australia, Japan, South Africa).
3) Incorporate the current health instrumentation (e.g. WHO) and collaborate with the dynamic population density groups.
4) Incorporate the annual load of cases treated (up to 2022).
5) Incorporate the seasonal-monthly load of cases treated (up to 2024).
6) Start real emergency operations with a triggering mechanism on day-visible-light and with night-time energy consumptions (up to 2025).

There is a clear role for EO in geo-locating HCF, but implementation schemes may be complicated and variable across settings. In low- and middle-income settings, EO data may not fully capture the informal health care services, which is probably already collected and available. In countries with advanced private health care system and security concerns, it will be difficult to use satellite imagery only, and a comprehensive map of HCFs may not be available for public use.

It is desirable to come up with an artificial intelligence 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 Horizon: The ENVHLTH-04-01 call on "Methods for assessing health-related costs of environmental stressors" allows a broader group of international research institutions to participate and mentions the use of environmental data and products coming from the satellite observations and the Copernicus Atmosphere Monitoring Service and the Copernicus Climate Change Service. A consortium with 15 European and US institutions plans to submit a proposal for developing four specific case studies that will advance the development of suitable modules from the aforementioned implementation flow.
- European Research Council: The 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.
- Robert Wood Johnson Foundation: These open calls – for public agencies, universities, and public charities – can provide overall description of project funding (e.g. US$150,000 to US$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; prioritize health as we design for changes in how we live, learn, work and play; and better understand new trends, opportunities, and breakthrough ideas that can enable everyone in the United States to live the healthiest life possible.
- Bloomberg Philanthropies: Bloomberg Philanthropies brings together people, ideas and resources from across sectors toward a common purpose and amplifying their impact. They focus on five key areas for creating lasting change – public health, environment, education, government innovation, and arts and culture – that help turn proven ideas into widespread solutions, and tailors them as needed to scale up their impact. Grant proposals are by invitation only.
- Belmont Forum: The Belmont Forum has launched 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.
- Other agencies – International Red Cross and Red Crescent and United States' agencies – may have interest and capabilities in this area.

Anticipated Risks:

1) The current tools from geographic services need adaptation and the development of deep learning models in order to extract the residential buildings and the perimeter of HCF.
2) Merging of several heterogeneous sources for identifying the global location of HCF.
3) Capabilities to assess the mortality and morbidity data in shorter than monthly updates with near-real time reporting tools.
4) Similar time frequencies for local climate and meteorological measurements will be essential from automatically operated monitoring and reporting facilities.

During the Fall Term 2020, a short case study over US counties was conducted at the Rensselaer Polytechnic Institute in order to examine the basis of current and future climate hazards for assessing the risks associated with the local health care infrastructure. Although this work was based on risk indices, it was evident that long temporal averaging influenced the conclusions and reduced the sensitivity of risks (Results: Effect of Precipitation on Health Care Facilities' Vulnerability and Healthcare Facility Flooding Information System).