Future Earth Observation Strategy for Societal Benefits

Guoqing Zhou and Oktay Baysal
Batten College of Engineering and Technology
Old Dominion University
Kaufman Hall, Rm. 214, Norfolk, VA, 23529
Tel: (757) 683-3619/3789, Fax: (757) 683-5655, Email: gzhou@odu.edu, obaysal@odu.edu

***Abstract* - This invited paper presents the future intelligent earth observing system (FIEOS) and event-driven earth observation concepts as well as their connections to societal benefits for both decision-makers and the general public. The elucidated linkage and flow of information from FIEOS to societal benefits is interoperable. With the envisioned FIEOS, this paper places an emphasis on (i) How to apply the FIEOS to increase the efficiency of monitoring natural disaster, to improve the natural disaster management, and to mitigate disasters through providing highly accurate, and reliable surveillance data for experts, analysts, and decision-makers; (ii) How to significantly increase and extend societal benefits to the future U.S. Earth observation application strategy in, for example, real-time response to time-critical events, and disastrous environmental monitoring. Therefore, this paper presents the analysis of FIEOS to society benefit in the realms: (i) reducing loss of life and property from natural and human-induced disasters, (ii) improving human health and well-being, (iii) improving wealth forecasting, (iv) supporting sustainable agriculture, and (v) serving lay people.**

I. INTRODUCTION

From the early simple missions to the sophisticated large satellite missions, a lot of facts have demonstrated that measurements from the earth observing system constitute a critical input when applying remote sensing technology for our societal benefit in such as enhancing human health, safety and welfare; alleviating human suffering including poverty and illness [14]; protecting the global environment, e.g., global warming; dust storm; and reducing losses of life and property caused by nature or/and human-induced disaster.

In order to further improve our ability to monitor, understand and predict changes to the our environment, and enhance our understanding of the complex working of the Earth system, including its weather, climate, oceans, atmosphere, water, land, geodynamics, natural resources, ecosystems, and natural and human-induced hazards, new earth observation strategy has continuously been presented for easily protecting our home planet and more efficiently and effectively managing our resources and infrastructure. For example, Bayal *et al.* [5], Zhou *et al.* [19] and Habib *et al.* [10] presented the architecture to the recently conceptualized “future intelligent earth observing system (FIEOS)", which substantially increase intelligent technologies into Earth observing system in order to improve the temporal, spectral, and spatial coverage of the area(s) under investigation and knowledge for providing valued-added information/data products to users. The envisioned future intelligent earth observing system (FIEOS) is especially significant for people, who want to learn about the dynamics of, for example, the spread of forest fires, regional to large-scale air quality issues, the spread of the harmful invasive species, or the atmospheric transport of volcanic plumes and ash [9]. However, there is little analysis for FEIOS to societal benefits. This paper attempts to state the challenging issue and its key application areas. A special emphasis is placed on: (i) how FIEOS increases the efficiency of monitoring natural disaster, to improve the natural disaster management, and to mitigate disasters; (ii) how FIEOS significantly increase and extend societal benefits to the future U.S. Earth observation application strategy in, for example, real-time response to time-critical events.

II. FUTURE EARTH OBSERVING STRATEGY

A. Intelligent Earth Observing Strategy

The envisioned FIEOS is a space-based architecture for the dynamic and comprehensive on-board integration of Earth observing sensors, data processors and communication systems. The implementation strategies suggest a seamless integration of diverse components into a smart, adaptable and robust Earth observation satellite system to enable simultaneous, global measurements and timely analyses of the Earth’s environment for a variety of users (Fig. 1). The architecture consists of multiple layer networked satellites. Each EO satellite is equipped with a different sensor for collection of different data and an on-board data processor that enables it to act autonomously, reacting to significant measurement events on and above the Earth. They collaboratively work together to conduct the range of functions currently performed by a few large satellites today through the use of high performance processing architectures and reconfigurable computing environments [1], [3-4]. The FIEOS will act autonomously in controlling instruments and spacecraft, while also responding to the commands of the user interested to measure specific events or features. So, users can select instrument parameters on demand and control on-board algorithms to preprocess the data for information extraction. All of the satellites are networked together into an organic

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measurement system with high speed optical and radio frequency links. User requests are routed to specific instruments maximizing the transfer of data to archive facilities on the ground and on the satellite. Such an earth observing system allows measurement from *in sit*u, air borne or space based sensors to be multiple practical usage that can help in making critical decisions for societal benefits.

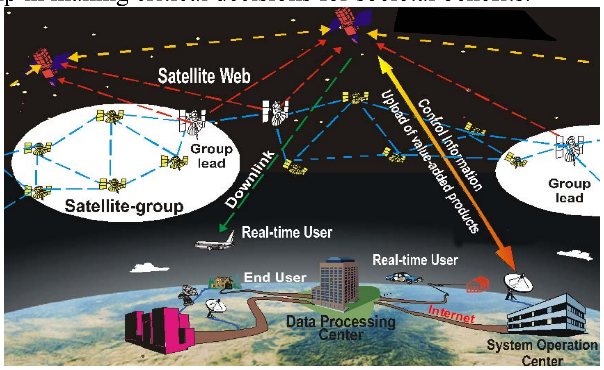

Fig. 1. The architecture of a future intelligent earth observing satellite system

B. Event-driven Earth Observation

The optimum earth observing system to meet the specific needs and mandates on specific and achievable societal benefits never stops. A called *event-driven observation* in FIEOS has been presented [18]. The operational mode is that each EO sensing system independently collects, analyzes and interprets data using its own sensors and on-board processors. When a sensing system detects an event, e.g., a forest fire, the sensing-satellite rotates its sensing system into position and alters its coverage area via adjusting its system parameters in order to bring the event into focus [13]. Meanwhile, the sensing-satellite informs member-satellites, and the member-satellites adjust their sensors to acquire the event, resulting in a multi-angle, -sensor, -resolution and -spectral observation and analysis of the event. These data sets are merged to a geostationary satellite according to the changes detected. Meanwhile, the geostationary further processes the data to develop other products, e.g., predictions of fire extend after 5 days, weather influence on a fire, pollution caused by a fire, etc. These value-added products are then transmitted to users.

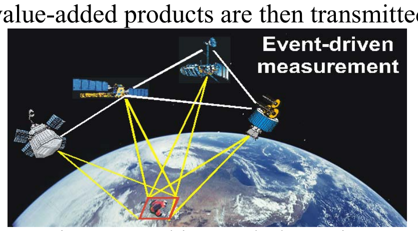

Fig. 2. Event-driven earth observation

III. SOCIETAL BENEFITS

The societal benefits from FIEOS are much clear to both decisions makers and the general public. This paper will place benefits in the following five areas as the preliminary focus.

A. Reduce Loss of Life and Property from Disasters

Natural hazards such as earthquakes, volcanoes, tornadoes, subsidences, avalanches, landslides, floods, wildfires, volcanic eruptions, extreme weather, coastal hazards, sea ice and space weather, tsunami, pollution events, are frequently happened in our home planet, resulting in severely losing a large number of life and property, and imposing a large burden on society [13]. For example, on 26 December 2004, 00:58:53 UTC, an 9.0 magnitude earthquake occurred on the seafloor near Aceh in northern Indonesia, causing a huge tsunami wave, hitting the coasts of Indonesia, Malaysia, Thailand, Myanmar, India, Sri Lanka, Maldives and even Somalia in Africa, resulting in Over 280,000 people lost their lives. The town of Lhoknga, near the capital of Banda Aceh, was completely destroyed by the tsunami.

It has been demonstrated that the losses of life and property from natural and human-induced disaster can be reduced through analysis of earth observing data. However, not all of disasters, such as tsunami, earthquake can so far be warned and predicted in advance, consequently, scientists have spent enormous efforts to exhaustively find thread of these complex natural phenomena from earth observing system in order to develop predictive measures so that people have enough time to prepare, plan, and response these disasters. Unfortunately, little progress has been made due to the lack of adequate measurements and the depth with which we fully understand the physics of these phenomena [9]. The current measurements and observations largely can not meet the demands of the disaster analysis. For example, scientists need worldwide DEM (digital elevation model) data with 1 m resolution for tsunami and flood analysis, and DEM data with 10 m resolution for earth crust deformation analysis.

The envisioned FIEOS demonstrates a prospective in cooperative operation of global coverage. The implementation of FIEOS will bring a more timely dissemination of information through web-based observing system for monitoring, predicting, risk assessment, early warning, mitigating, and responding to hazards at local, national, regional, and global levels. For example, the traditional earth observing systems are not capable of collecting high-resolution (less than 3 meter) multispectral data in a specific wildfire area at a repeat cycle of 15 minutes, while the FIEOS has networked ground-based, air-based and space-based three-dimensional observation system. Thereby, high-resolution, multispectral data can be provided in a manner of real-time observations and immediate measurement to a specific event.

B. Improve Human Health and Well-Being

The average life of people living in 21st century has been twice as long as the people living last century. Improvement of environmental factors such as sanitation and clean water, the propagation and breakout of infectious disaster, etc, is an important factor to increase the life. For those diseases, such as infectious diseases, that are influenced by environmental factors, the application of earth observing system provides an additional avenue, by which the environmental information related to diseases can be extracted and then transformed into measures of environment factors impacting human health and well-being [9]. For example, West Nile Virus (WNV) was first detected in the United States from tissues of dead birds in New York City in 1999, but it originated from Africa in 1937. Our research group has deployed an initial research in mosquito vector surveillance and control via the integration of Landsat-7 ETM+ imagery in combination with the other ancillary data (such as USGS DEM, Radarsat SAR imagery) to estimate the spatial distribution and density of mosquito populations and measured environmental factors related to mosquito habitant e.g., land surface temperature, rainfall, vegetation index [2].

The research results demonstrated that the improvement must be carried out via superior temporal resolution imagery because some adult mosquito life cycle, e.g., California mosquito, is only 10 days at 80° F, and 14 days at 70° F, and some of adult male mosquitoes is 6-7 days (some of adult female mosquitoes is 2-16 weeks), while the Landsat 7 ETM+ repeat cycle is 16 days, which do not cover an entire life cycle of mosquito. MODIS (Moderate Resolution Imaging Spectroradiometer) onboard the Terra satellite provides a unique chances for investigating short life cycle targets to improve and enhance our understanding to mosquito breeding because of its 1.2 day temporal resolution and high spectral resolution (36 bands). However the ground resolution of MODIS is too low so that it is hard to obtain high density of parameters related to mosquito vectors.

The envisioned FIEOS is able to assist field mosquito vector surveillance and control because it is capable of providing bi-daily, weekly, biweekly, monthly, seasonal mosquito distributions and accurate regionalization of mosquito abundance, potentially species distributions, and precise locations and conditions of disease transmission via observations from the ground-, air- and space-based sensing system and intelligent knowledge. Consequently, researchers, service providers, policy makers and the public can understand environmental factors in order to improve surveillance activities (e.g., location of mosquito traps and sentinel chicken flocks) and control (source prevention, spraying, and larviciding), and make decisions and take actions to break the transmission paths. With intelligent technology, the FIEOS would give us the capability to predict the outbreak of deadly diseases by tracking the environmental factors that contribute to their spread.

C. Improve Weather Forecasting

Although weather satellite observing system, along with the other associated national and international data management mechanisms, is probably most mature relative to other observing systems, the improvement of accuracy of weather-forecasting, the enhancement of observations (e.g., wind and humidity profiles, precipitation), the improvement of long-term weather forecasting, and the access and delivery of essential weather forecast products to user for meeting requirements of timely short- and medium-term forecasts are still urgently essential for societal benefit [6].

The shortcoming of the current earth observing system is that its spatial, temporal-, and spectral resolution and sensing capability can not obtain sufficiently high accurate, gridded worldwide weather [6], resulting in that the different weather users, such as real-time, mobile users, can not dynamically access the desired data in an near instantaneous and global access manner. The envisioned FIEOS observing system is capable of providing users to near instantaneously access to worldwide weather data for a given point, a path, or an area in time and space anywhere in the world via satellite broadcast or direct send/receive satellite link. Especially, FIEOS provides the weather forecasting data with different levels of scales: macro-scale, smaller-scale, and micro-scale. At the macro-scale level, users, such as commercial airlines pilot, can obtain weather forecasting information from forecast centers via wireless. At the small-scale level, user can directly obtain weather forecasting products from a forecast or data processing center via either wireless or wire access. Alternatively, the user can also gain access to the database(s) described weather information to generate his or her own weather products using wireless/wire user software. For those mobile users, including truck drivers, farmers, and private car owners, they can receive the broadcast weather information directly from the forecasting information center using hand-held device. The devices can also be designed to have a direct send/receive satellite transmission capability, and the broadcast center may be local TV, universities, and radio stations, etc.

D. Support Sustainable Agriculture

World population will increase by roughly 50% in the next 50 years, which presents increasing demands on crucial resources like food [15]. Food product is influenced by factors, such as water and weather patterns in the changing climatic conditions, agricultural technologies, market forces and investment [14]. Agriculturists around world measure information related to food products, such as soil type, timely and accurate seasonal and longer-term trends of climatic conditions, e.g., temperature, humidity, and rainfall patterns using earth observing system. Although the current high resolution satellite imagery can provide tremendous knowledge to generate forecast for the food product, the improvement of observations, models, and predictions of critical parameters (such as weather, salinity, erosion and soil loss, fires, pests and invasive species) are essential to help us to mitigate these effects on farms. The envisioned FIEOS observing system is expected to provide not only the information mentioned above, but also valued-added products, such as crop production, livestock, aquaculture and fishery statistics; food security and drought projections; nutrient balances; farming systems; land use and land cover change; and changes in the extent and severity of land degradation and desertification through FIEOS observation from *in situ*, air and space, intelligent technology as well as integration of early food production database and production models. Moreover, with FIEOS expert system, FIEOS is also expected to generate global food product prediction, poverty and food monitoring, and international planning, to help us know in advance when droughts would occur and how long they would last and their influences on food product. Especially, FIEOS can monitor and warn those floods that lead to a major destruction of both human life and agricultural land, clearly monitor the progress of these catastrophic events, to help us to see and predict what impact food products during the next several years.

E. Serve Lay User

The obvious shortcoming of the current earth observing system is that the lay users can not actively be involved. Relatively, one of the benefits of FIEOS lies in its broad range of user communities, including managers and policy makers in the targeted societal benefit areas, scientific researchers, engineers, governmental and non-governmental organizations and international bodies**.** In particular, FIEOS would serve lay users who directly receive satellite data (in fact, the concept of data means image-based information, rather than traditional remotely sensed data) using their own receiving equipment. The operation appears to the end-users as simple and easy as selecting a TV channel by using a remote control (Fig. 3). Moreover, the authorized users are allowed to upload the user's command for accessing and retrieving data via on-board data distributor according to the user's requirement and position [18]. In this fashion, a lay user on the street is able to use a portable wireless device to downlink/access the satellite information of his surroundings from satellite or from the Internet. Homes in the future are also able to obtain atmospheric data from the satellite network for monitoring their own environments. The FIEOS will enable people not only to see their environment, but also to "shape" their physical surroundings.

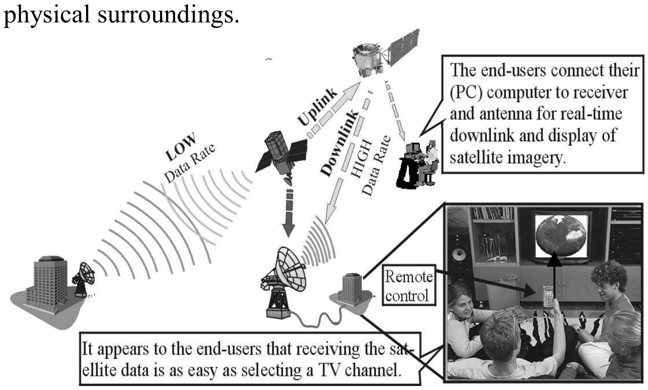

Fig. 3. Lay-user receive the satellite inforamtion just like selecting a TV channel.

IV. CONCLUSION

Although significant advances in our ability to measure and understand the Earth using earth observing system have been obtained, the emergency task should is to build an intelligent, comprehensive, integrated, and sustained earth observation system, despite remaining multiple technical challenges, to ultimately realize a wide range of benefits for our people, our economy, and our planet. This paper just starts from this point. The envisioned FIEOS is intended to enable simultaneous, global measurements and timely analyses of Earth's environments for a variety of users through dynamic and comprehensive on-board integration of Earth observing sensors, data processors and communication systems.

FIEOS provides the nation with a unique and innovative perspective on the intelligent observing system and its societal benefits in such as (1) reducing losses of life and property; (2) improving human health and well being; (3) improving weather forecasting; (4) supporting sustainable agriculture; and (5) serving lay users. Implementing FIEOS is an exciting opportunity to make lasting improvements in U.S. capacity to deliver specific benefits to our people, our economy and our planet.

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