FUTURE INTELLIGENT EARTH OBSERVING SYSTEM (FIEOS) FOR FAST RESPONSE TO DISASTER

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ABSTRACT:

This invited paper presents the future intelligent earth observing system (FIEOS) and event-driven earth observation concepts as well as their connections to disaster response for both decision-makers and the general public. The elucidated linkage and flow of information from FIEOS to societal benefits is interoperable and easily expanded. With the envisioned FIEOS, this paper emphases on (i) How to apply the FIEOS and the event-driven observation to increase the efficiency of monitoring natural disaster, to improve the natural disaster management, and to mitigate disasters through providing highly accurate, and to provide highly 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, surveillance, real-time response to time-critical events, and disastrous environmental monitoring. Therefore, this paper presents the analysis of FIEOS to society benefit in the in the realms: (i) reducing loss of life and property from natural and human-induced disasters, (ii) understanding the effect of environmental factors on human health and well-being, (iii) improving wealth forecasting, (iv) supporting sustainable agriculture, and (v) serving lay people.

1. INTRODUCTION

A lot of facts have demonstrated that measurements from the earth observing system constitute a critical input for such as enhancing human health, safety and welfare; alleviating human suffering including poverty and illness (Strategic Plan, 2004); 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 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. It has proudly seen that US is leading and developing a Global Earth Observation System that involves 48 other countries, the European Commission and 29 international organizations. According to a press release from the president's Office of Science and Technology Policy (OSTP), the United States drafted a 10-year Strategic Plan for the U.S. Integrated Earth Observation System (Strategic Plan, 2004). This draft strategic plan is a critical first step toward integrating thousands of individual pieces of observation technologies for tracking environmental changes in every part of the globe, enabling citizens and leaders to make more informed decisions about their lives, environment and economies (Strategic Plan, 2004). The draft plan also offers a vision, which proposes that earth observation should benefit people and economies around the world through an integrated, comprehensive, sustained Global Earth observation system. At this point, this Strategic Plan will leverage and coordinate the interested countries' and organizations' efforts, address the critical gaps, support their interoperability, share information, and improve the delivery of information to users to reach a common understanding of user requirements.

Oktay *et al.* (2004), Zhou *et al.* (2004) and Habib *et al.* (2004, 2003) 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. However, there is little analysis for FEIOS to societal benefits and costs, and addressed optimum set of sensors needed to make the necessary observations for a specified event. This paper attempts to state these challenging issues and presents FIEOS' dynamic spatial, spectral, and temporal characteristics as well as 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 through providing highly accurate, and highly reliable surveillance data for experts, analysts, and decision-makers; (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, and disastrous environmental monitoring.

2. FUTURE EARTH OBSERVING STRATEGY

Zhou *et al.* (2004) presented the architecture and concept of the future intelligent earth observing satellite (FIEOS), which is a space-based architecture for the dynamic and comprehensive on-board integration of Earth observing sensors, data processors

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and communication systems. The architecture and implementation strategies suggest a seamless integration of diverse components into a smart, adaptable and robust Earth observation satellite system. It is intended to enable simultaneous, global measurements and timely analyses of the Earth's environment for a variety of users (Figure 1).

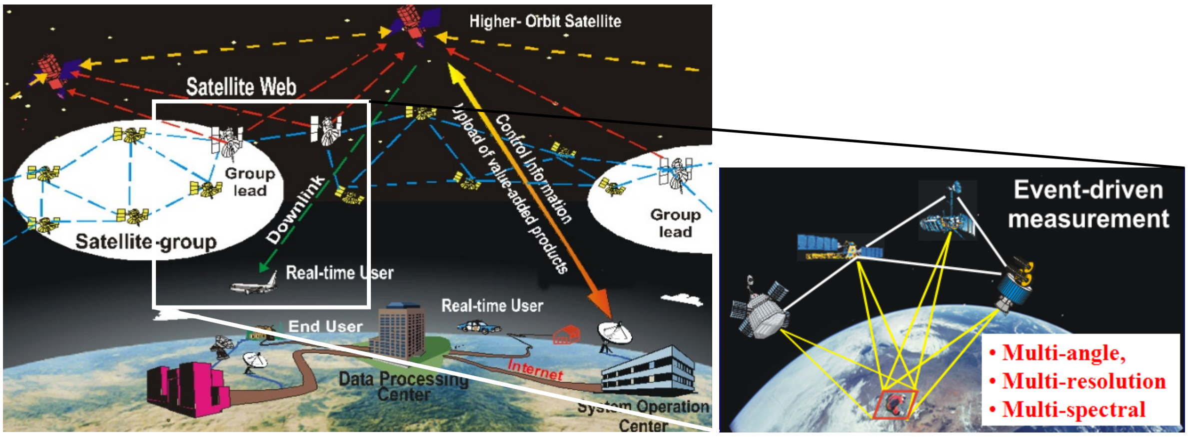

Figure 1. The architecture of a future intelligent earth observing satellite system and event-driven earth observing system

This FIEOS was envisioned as multiple layer satellite network. The two main lays are low-orbit satellites and high-orbit satellite. The first main layer, which consists of hundreds of earth observing satellites (EOSs) viewing the entire earth, is distributed in low orbits ranging from 300 km to beyond. Each EOS is small, lightweight and inexpensive relative to current satellites. These satellites are divided into *satellite groups*. Each EOS 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. There is a lead satellite in each group, called *group-lead*; the other satellites are called *member-satellites*. The group-lead is responsible for management of the member-satellites and communication with other group-leaders in the network (constellation) in addition to communication with the geostationary satellites. This mode of operation is similar to an *intranet.* The group-lead looks like a local server, and the member-satellites look like the computer terminals. The local server (group-lead) is responsible for internet (external) communication in addition to management of the intranet (local) network. This design can reduce the communication load and ensure effectiveness of management and coverage of data collection. The second main layer is composed of geostationary satellites because not all EOSs are in view of or in communication with worldwide users. The second layer satellite network is responsible for communication with end-users (e.g., data downlink) and ground control stations, and ground data processing centers, in addition to further processing of data from group-lead satellites. All of the satellites are networked together into an organic 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 (Prescott *et al.*, 1999). Thus, all group-leads must establish and maintain a high-speed data cross-link with one another in addition to uplink with one or more geostationary satellites, which in turn maintain high-speed data cross-links and down-links with end users and ground control stations and processing centers. 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 the societal benefits.

Especially, the FIEOS developed a called *event-driven observation*. The operational mode is the normal operating procedure is for each EOS to independently collect, analyze and interpret data using its own sensors and on-board processors. These collected data will *not* be transmitted to ground users, the ground station, or geostationary satellites unless they detect changed data. When an EOS 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 (Schoeberl *et al*., 2001). Meanwhile, the sensing-satellite informs member-satellites in its group, 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 that assigns priority levels according to the changes detected. Following a progressive data compression, the data is then available for transmission to other geostationaries. The links between the geostationary satellites provide the worldwide real-time capability of the system. 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 also transmitted to users. Thus, the FIEOS will perform much of the event detection and response processing that is presently performed by ground-based systems through the use of high performance processing architectures and reconfigurable computing environments (Alkalai, 2001; Armbruster et al., 2000; Bergmann et al., 2000).

3. SOCIETAL BENEFITS OF DISASTER RESPONSE

The societal benefits from FIEOS is much clear to both decisions makers and the general public, since (1) the instruments and platforms in FIEOS are organically tied together with network information technology; (2) the constellation (multi-layer satellite network) insures that global data is collected on a frequency of decade minutes base or shorter; (3) event-driven data are collected with multi-angle, multi-resolution, multi-bands; and (4) users can acquire images of any part of the globe in real-time. Therefore, this FIEOS is expected to be capable of

(1) Improving our ability to monitor, understand, and predict changes to the complex working of Earth system,
(2) Enabling citizens and leaders around world to make more informed decisions affecting their lives, environment, and economies to improve our economic prosperity and quality of life,
(3) Predicting droughts, preparing for weather emergencies and other natural hazards, planning and protecting crops, managing coastal areas and fisheries, and monitoring air quality.

3.1 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, and 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 (Strategic Plan, 2004) . In the US, the economic cost of disasters averages $20 billion dollars per year (Van *et al.*, 1998). On 26 December 2004, 00:58:53 UTC (7:58:53 am local time), an 9.0 magnitude earthquake occurred on the seafloor near Aceh in northern Indonesia (The epicentre was located at 3.32º N, 95.85º E). This earthquake generated 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. Aceh, located on the northern tip of the island of Sumatra, Indonesia, was hit hardest by tsunamis. The town of Lhoknga, near the capital of Aceh, Banda Aceh, was completely destroyed by the tsunami (Figure 4).

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 (Hibib *et al*., 2004). In order to provide early warning capability for disasters, the different sources of data from natural environment, and human infrastructure, along with real-time and accurate observations and measurements from ground, air, and space as well as a prediction model must simultaneously be provided. Strategic Plan (2004) summarized the main problems (technical gap) between the 10 natural disasters and the current observation capability. As seen from the statement, the current measurements and observations largely can not meet the demands of the 10 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. However the fact is the DEMs with global coverage and the different resolutions are no available.

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.

3.2 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. The ability to predict the disease emergence and intensity has long been a dream of public health workers, economic planners and ordinary citizens (Habib *et al.*, 2004). Improvement of environmental factors such as improving sanitation and clean water, controlling the propagation and breakout of infectious disaster, cleaning air, and safe use of chemical medicine, etc, is an important factor to increase the life. For those diseases, such as infectious diseases and epidemics, that are influenced by environmental factors, the development of predictive models will provide the chance for people to predict occurrence in order to effectively control or prevent these diseases from human populations. 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. As a result, they will be used for supporting or improving the existing predictive models of diseases. Recent studies have shown that monitoring non-infectious respiratory disease can also benefit from earth observation in predicting near term Asthma illnesses in certain geographic areas (Habib *et al*., 2004).

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, and spread out into Europe, the Middle East, west and central Asia and associated islands afterward. In 2002, more than 170 people in the US have died from WNV. It has been demonstrated that over 25 species of mosquitoes have tested positive for WNV transmission, and the *Cules* species mosquito seems the most common species associated with infecting people and horses (Allen *et al*., 2003). The researchers and organization is using the remotely sensed images for the field mosquito spatial distribution and population mapping in conjunction with clinical surveillance provides a detailed, accurate product in a time and cost effective manner because the remotely sensed imagery could provide relevant surrogate information and variables such as land surface temperature, rainfall, vegetation index, etc. (Wood *et al*., 1992; Imhoff *et al.*, 1988). 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. The project has established a database of mosquitoes obtaining by the field and laboratory specimens of mosquitoes, associated serological analysis using spatial coverage, terrain morphometry and moisture indices, and a seasonal time series of Landsat 7 ETM+ imagery.

The research results demonstrated that the improvement must be carried out via superior temporal resolution imagery (Allen *et al.*, 2003) because some adult mosquito life cycles, such as California mosquito, are only 10 days at 80° F, and 14 days at 70° F, and some of adult male mosquitoes are 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. The MODIS (Moderate Resolution Imaging Spectroradiometer) onboard the Terra satellite provides a unique chance for investigating short life cycle targets, such as the *California mosquito* opportunity for us to improve mosquito mapping capability and accuracy, 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 landscape of mosquito control is a continually fluctuating, complex one, where mosquito species, viruses, and their hosts/vectors and humans are in constant motion (Allen et al., 2003). The disconnections between human health surveillance, mosquito surveillance, and birds and other reservoir populations are enormous. The current earth observing system can not meet this demand. The envisioned FIEOS is able to assist field mosquito control operations and 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 and potentially species distributions and also providing 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 and protecting the population. Moreover, with intelligent technology of FIEOS, the FIEOS would give us the capability to predict the outbreak of deadly diseases by tracking the environmental factors that contribute to their spread.

3.3 Improve Weather Forecasting

Accurate weather forecasting is critically important to the societal benefits. Every country has its weather service center for weather forecasting in order to mitigate loss of life and property. 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 and earth-sensing information (US Air Force 2004), resulting in 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 instantaneous 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 airline pilots, can obtain weather forecasting information from forecast centers via wireless, and the forecasting center can acquire observational data from data processing centers, who produce the forecast products via earth observing system including analysis model. At the small-scale level, users can directly obtain weather forecasting products from a forecast or data processing center via either wireless or wire access. Alternatively, the users 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 a 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. This attribute will enable the specific users to obtain specific weather information via direct query access to the information center.

3.4 Support Sustainable Agriculture

Food product is influenced by factors, such as water and weather patterns in the changing climatic conditions, and management practices, agricultural technologies, market forces and investment (NASA, 2004). Earth observing system offers a great promise in obtaining synoptic, consistent, and repetitive factors related to food product. For example, drought and extreme weather information decrease food production, and the spectral information can be related to canopy chemistry and/or temporal changes and carbon stock. Although the current high resolution satellite imagery can provide tremendous knowledge assessing the present conditions in the fields and provide necessary initial conditions to generate forecast for the food product, 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, ground, 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. In addition, the recent earth observing system can not monitor and warn those floods that lead to a major destruction of both human life and agricultural land. FIEOS observing system would be capable of clearly monitoring the evolution and progress of these catastrophic events, to help us to see and predict what impact food products during the next several years.

3.5 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, such as those assisting with the implementation of multilateral environmental agreements**.** 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 (Figure 4). Moreover, the authorized/licensesed 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

(Zhou et al., 2004).

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 intelligent satellite system will enable people not only to see their environment, but also to "shape" their physical surroundings. For this purpose, users need:

(1) **User Software for Data Downlink:** For a lay user (e.g., a farmer) complicated application software is unnecessary because the user analyzes and interprets the images using their perceptual faculties. For more advanced users (e.g., a professor), advanced software will still be necessary because they use "imagery" in different ways.

(2) **Accessible Frequency:** Different users need different imagery, e.g., a photogrammetrist needs forward and afterward stereo panchromatic imagery for stereo mapping; a biologist needs hyperspectral imagery for flower research. Thus, different types of satellite images are assigned with different broadcast frequencies, which the ground control station provides access to for authorized users.

(3) **Resolution Requirement:** Different users need different resolution of imagery. After end-users upload their command of resolution requirement, on-board processors and distributors will resample the original images into the resolution required by end-users, and distribute the data to the end-users.

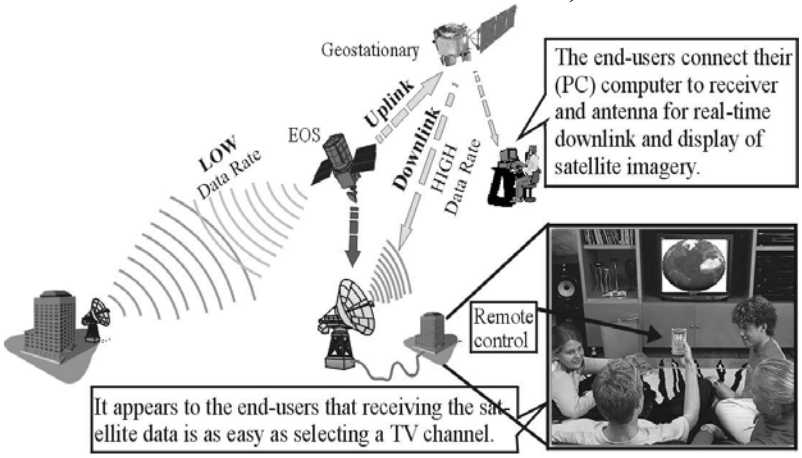

Figure 2. Lay-user receive the satellite inforamtion just like selecting a TV channel.

4. CONCLUSION

Although significant advances to measure and understand the Earth using earth observing system have been obtained, building an intelligent, comprehensive, integrated, and sustained earth observation system remains multiple technical challenges. The emergency task should migrate from the current capability improvement of sensing system to integrated approach, and 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 observing system is a space-based architecture for dynamic and comprehensive on-board integration of Earth observing sensors, data processors and communication systems. It is intended to enable simultaneous, global measurements and timely analyses of Earth's environments for a variety of users. The FIEOS would also help us to protect and manage natural resources, adapt to and mitigate climate variation, support sustainable forecast weather, and protect areas valued for the public. 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. The future is promising. Hopefully, this revolutionary concept will impact dramatically how earth observing system develops and conducts missions in the next few decades.

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