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Future Intelligent Earth Observing Satellite System (FIEOS): Advanced System of Systems

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1. Introduction

Diverse natural disasters such as earthquakes, volcanoes, tornadoes, subsidences, avalanches, landslides, floods, wildfires, volcanic eruptions, extreme weather, coastal disasters, sea ice and space weather, tsunami, pollution events, have ravened many lives and damaged a number of properties each year in our home planet, resulting in imposing heavy burden on society [13]. For example, a deadly 8.0 Ms Wenchuan earthquake occurred at 14:28:01.42 on May 12, 2008 in Sichuan province of China has killed at least 69,197, injured 374,176, made 18,222 missed, and gave rise to about 4.8 million people homeless; a 9.0 magnitude earthquake occurred on the seafloor near Aceh in northern Indonesia on 26 December 2004, 00:58:53 UTC, 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 disaster can be reduced through analysis of earth observing data acquired by spaceborne. 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 seek for 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], i.e., the current measurements and observations largely cannot meet the demands of the disaster warning.

In order to increase our ability to monitor and predict natural disasters, Zhou *et al.* [18] in the early 2000 presented an envisioned architecture, named *"future intelligent earth observing satellite system (FIEOS)*". Afterwards, Bayal *et al.* [5] and Habib *et al.* [10] presented the similar concepts. The FIEOS would 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 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]. The FIEOS is honored as advanced global earth observing system of systems (GEOSS). This paper attempts to state *(i)* what the challenges of "traditional" GEOSS are; *(ii)* how FIEOS (advanced GEOSS) increases the efficiency of monitoring natural disaster, to improve the natural disaster management, and to mitigate disasters; *(iii)* how the FIEOS can enhance our understanding to Earth system and Earth progress; *(iv)* how the FIEOS significantly benefits the disaster reduction through, for example, real-time response to time-critical natural disaster.

2. "Traditional" Global Earth Observing System of Systems (GEOSS) and Challenges

In order to improve our capability of understanding of the Earth system, and enhance prediction of the natural disaster, an agreement for a 10-year implementation plan for a Global Earth Observation System of Systems, known as *GEOSS,* was reached by member countries of the Group on Earth Observations at the Third Observation Summit held in Brussels on February 16, 2005. The GEOSS was envisioned as an international cooperative effort to bring together existing and new technologies in hardware and software, making it all compatible in order to share data and information worldwide at no cost. All subscribing nations maintain their independent role in developing and maintaining the system, collecting data, analyzing data, enhancing data distribution, etc. (www.codata.org/GEOSS/capetown-meeting.html). With such an envisioned architecture, the GEOSS is anticipated to meet the need for timely, quality long-term global information for sound decision making for, and enhance delivery of benefits to society relating to disaster preparedness.

Meanwhile, the US 10-year Strategic Plan for the U.S. Integrated Earth Observation System was publicly presented by the President's Science Advisor on September 8, 2004. The Plan addressing nine societal benefit areas include [19]:

- Improvement of weather forecasting
- Reduction of loss of life and property from disasters
- Protection and monitor our ocean resources
- Understanding, assessment, prediction, mitigation and adaption to climate variability and change
- Support of sustainable agriculture and combination of land degradation
- Understanding of the effect of environmental factors on human health and well-being
- Development of the capacity to make ecological forecasts
- Protection of and monitoring of water resources
- Monitoring and management of energy resources

The characteristics of the above strategies lie in as follows.

1. Improve current capability, needs, and deficiencies of satellite/air/ground imaging systems in order to integrate global systems, joint data collection, and behavioral modeling initiatives, etc.,
2. Improve data collection to increase our understanding of how disasters evolve and to assess current phenomena of natural disaster,

3. Improve data processing capability and techniques and data/information visualization techniques in order to develop better models to make prediction model more accurate,
4. Establish global disaster reduction & warning system in order to make the results more precise, and
5. Establish national all-disasters emergency communication system in order to make all disaster information accessible and warn citizens with consistent, accessible, and actionable messages.

The GEOSS is promising. However, because of the complexity of Earth processes and mechanism of natural disaster, the requests for earth observing system has shifted from previous imaging mode, spatial resolution, spectral resolution, revisit capability, etc. to on-board data processing, event-driven data collection, value-added products, etc. (see Figure 1). This means that a much advanced earth observing system is needed.

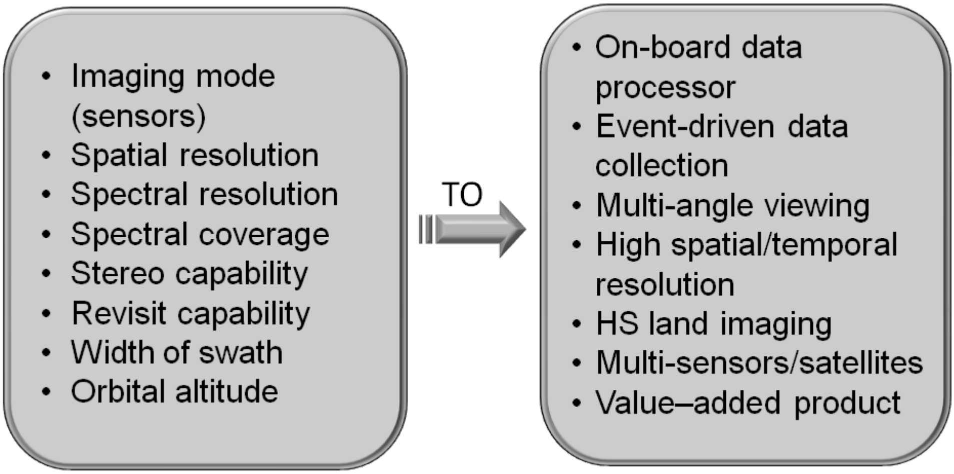

Fig. 1. The features for disaster monitoring in future earth observing system of systems

3. Future Intelligent Earth Observing Systems - FIEOS

3.1 Architecture of intelligent Earth observing satellite system - FIEOS

As mentioned above, the GEOSS has its limits in rapid response to time-critical natural disaster. Thereby, a much advanced earth observing system, called future intelligent earth observing system was proposed by Zhou in 2000 [18]. 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. 2). 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 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.

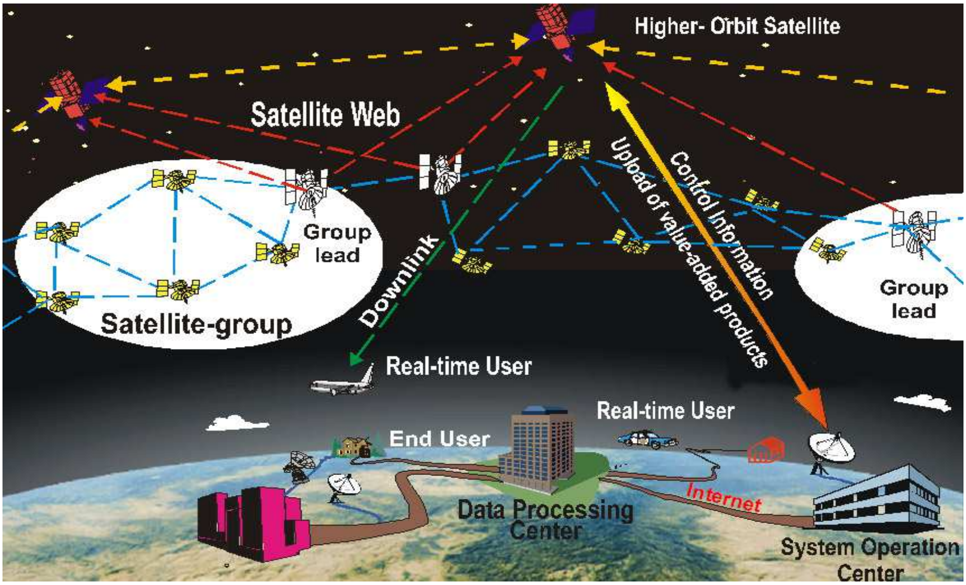

Fig. 2. The architecture of a future intelligent earth observing satellite system (courtesy of Zhou et al. [18])

3.2. Event-driven Earth observation

The optimum earth observing system to meet the specific needs and mandates on specific and achievable societal benefits never stops [10]. 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 (Fig. 3). 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. The details of the event-driven Earth observation can be referenced to Zhou et al. [18].

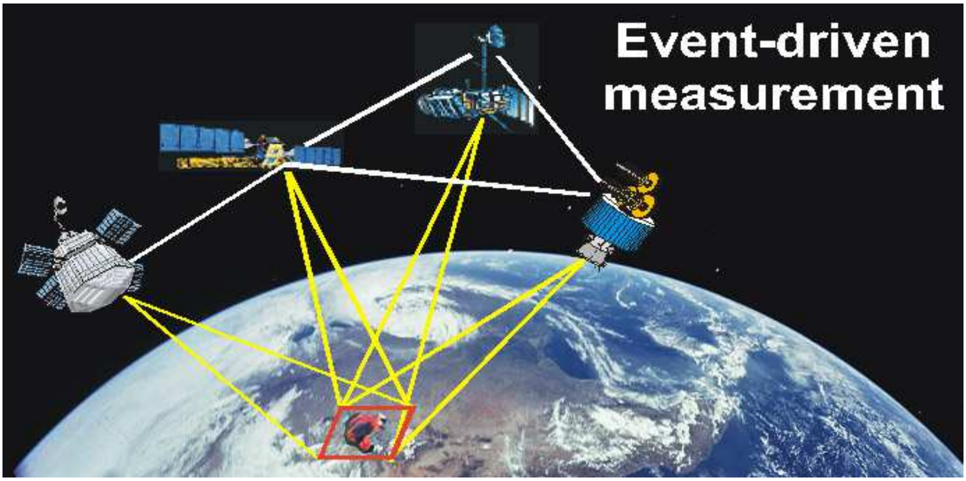

Fig. 3. Event-driven earth observation

4. Disaster Reduction from FIEOS

The significant characteristic of FIEOS is its capability to rapid response to time-critical disaster, relative to the GEOSS. Thus, the FIEOS largely benefits to both decisions makers and the general public for disaster prediction and disaster preparedness. As an example, this paper describes how the FIEOS improve weather forecast for reduction of disaster.

4.1 Reduction of disaster through improvement of weather forecast

The improvement of weather forecast will largely enhance prediction of disasters caused by extreme weather, such as flooding, landslide, etc. 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 natural disaster reduction [6].

The shortcoming of the current earth observing system is that its spatial, temporal-, and spectral resolution and sensing capability cannot obtain sufficiently high accurate, gridded worldwide weather [6], resulting in that the different weather users, such as real-time, mobile users, cannot 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-meso-micro level. At the macro-scale level, users, such as commercial airlines pilot, can obtain weather forecasting information from forecast centers via wireless. At the meso-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.

4.2 Dissemination to lay user

The obvious shortcoming of the current earth observing system is that the lay users cannot 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. 4). 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.

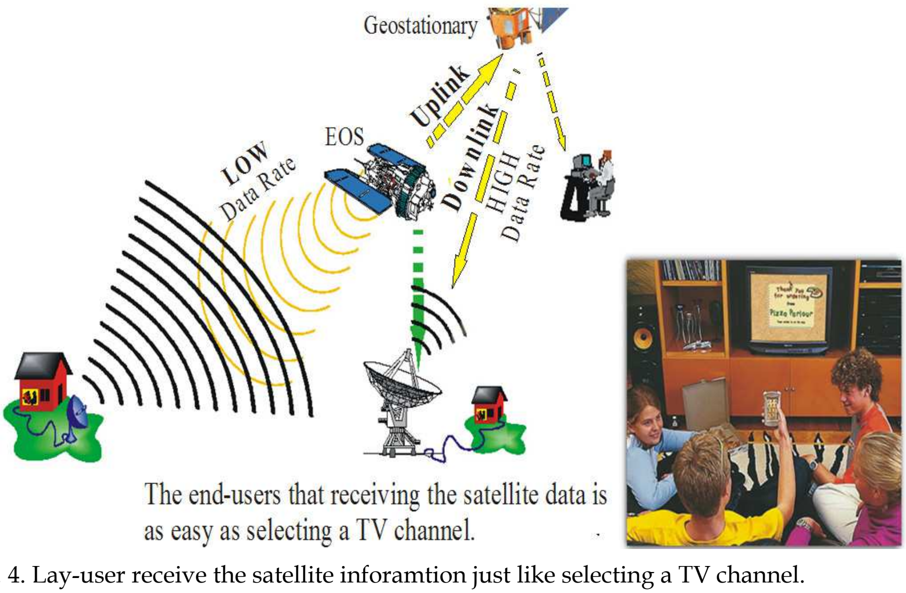

Fig. 4. Lay-user receive the satellite inforamtion just like selecting a TV channel.

5. Conclusions

Although significant advances in our ability to measure and understand the Earth system and process 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 disaster reduction. This paper presented an envisioned FIEOS which 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 for disaster reduction for (1) reducing losses of life and property; (2) improving weather forecasting; and (3) disseminating information to lay users. Realization of FIEOS, which is a much advanced GEOSS, is an exciting opportunity to make lasting improvements in delivering prediction of disaster to our people.

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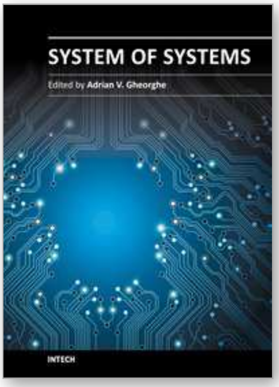

System of Systems

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The present book proposes and fosters discussion on the current applications in the field of system of systems, with emphasis on the implications of the fact that new developments and area of technical and non-technical applications are merging. The book aims to establish an effective platform for communication among various types of practitioners and theory developers involved in using the system thinking and systems engineering approaches at the scale of increased complexity and advancing computational solutions to such systems.

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