Tsunami Warning System with Sea Surface Features Derived from Altimeter Onboard Satellites

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***Abstract*—A tsunami warning system based on active database system with satellite derived real-time data of tidal, significant wave height and ocean wind speed as well as assimilation data of sea level changes as one of the global risk management systems is proposed. Also, Geographic Information System (GIS) with free open source software of PostGIS is proposed for active database system. It may be said that the proposed tsunami warning and evacuation information provided system is recommendable.**

Keywords*—Active database system; ocean related data stream; assimilation data; altimeter onboard satellites; Geographic Information System (GIS), tsunami

I. Introduction

There is a strong desire for disaster warning systems to mitigate disaster as well as secondly disaster, for the warning systems for earth quake, tsunami, flooding, hurricane and so on. Important thing for that disaster mitigation is the timeliness and comprehension. All the required data and information must be collected in a timely manner and transmit warning related information in a comprehensive manner. Thus, online database system, or active database[1] and Geographic Information System (GIS)[2] are needed for that. Thus, the system for making warning should include the followings:

1) gathering disaster related data as a data stream,
2) calculating and extracting information for making decision of warning from the data stream, and
3) transmit the warning information to the peoples who are living in the dangerous areas which contains information for evacuation as well as disaster recovery. For such warning systems need the followings:

- Active database systems [1].
- The required real-time data for decision making of warning and evacuation.
- Communication links [2] which allow acquisition of the real-time data and transmit warning information [3]-[5].

One of the key issues on active database systems is query creation. There is some query create software for SQL[3] based database systems. Customizing GIS system for disaster warning system is the other key issue [6], [7]. Other than these, interface between GIS and the existing database systems [8] and communication media are another important issue. The following section describes the proposed ocean related disaster warning system followed by customizing the existing GIS system. Then an example with satellite derived sea level, significant wave height and wind speed data for tsunami warning system is proposed together with assimilation[4] data based warning system.

II. Proposed Method

A. Proposed Tsunami Warning System

The proposed tsunami warning system is composed with the following four components,

1) data acquisition system,
2) data stream acquisition and active database system,
3) decision making software, and
4) alert/warning and evacuation related data and information transmissions.

Automated alert/warning system that enables real time warning of tsunamis would enable timely evacuation from possibly hazardous coastal areas, save precious human lives and avoid miseries for millions. A tsunami warning preparedness and evacuation system is proposed as is shown in Fig. 1. Tidal height, Earthquake event, Sea level changes and the other sea surface conditions can be gathered from the satellite data servers, tsunami warning center and handheld pager, mobile phone cameras. Key issue here is active database which allows real-time data access between data and information server.

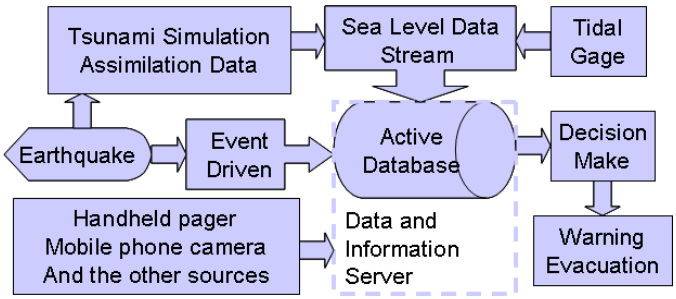


Fig. 1. Tsunami warning and evacuation information with map attributes provides system.

[1] https://en.wikipedia.org/wiki/Active_database
[2] https://www.gislounge.com/
[3] https://dev.mysql.com/downloads/
[4] http://www.dictionary.com/browse/assimilation

The sea level changes measuring device needs to be so small that people can carry it anywhere. It could be connected to mobile phone or handheld mobile terminals for real time information about the tsunami and guiding people to safer locations from the tsunami would occur. The integrated system would provide information about sea wave height and direction, using the same data as that used for modeling tsunami (assimilation data). A handheld mobile terminal with a mobile phone and General Packet Radio Service: GPRS[5] or Worldwide Interoperability for Microwave Access: WiMAX[6] and or WiMax2 is used to develop a wireless GIS.

This system will also comprise advance gadgets such as Bluetooth GPS and a digital camera. An internet map server is developed which contains GIS data on coastal zone land use land cover maps with all attributes. These maps are updated using high resolution satellite data.

The server is interfaced with a coastal hydraulic modeling system. Coastal hydraulic modeling system[7] receives sea level changes data from the measuring towers at regular interval in a real-time basis. This data is used for forecasting wave height and direction at different locations along with the coastline. This information is served online in real time, and is displayed on handheld system or mobile phone in the form of a simulated map.

In the event of a tsunami, the system is forecast a warning for coastal areas about to is inundated, including the time at which the tsunami is expected. The most important feature of the system in the event of evacuation is that this module is display a map with safer locations and roads to reach those locations. Data Acquisition System

Disaster related real time data has to be gathered and acquired in a timely manner. Revisit cycle of the satellite orbit, more than 10 days is far from the required period for disaster warning, every 10 minutes or so. Although data assimilation is available, mesh size of assimilation data is course, every 30' or so and time interval, hourly is much longer than the required period.

The most desirable data acquisition system would be dedicated system for the specific disaster. For instance, tide gages on the tower situated at the possible areas of the tsunami for tsunami warning system. Along with the fire ring in the Pacific Ocean, there are possible areas of earth quake followed by tsunami. Therefore, if the tower is set along with the possible coastal areas, then disaster due to tsunami might be mitigated.

B. Data Stream Acquisition and Active Database System

Free Open Source Software: FOSS of GIS, Post GIS is a possible candidate of GIS system [10]. Table 1 shows widely available GIS systems. For active database system creation, PostGIS[8] with MapServer[9] is selected.

[5] https://www.lifewire.com/general-packet-radio-service-817466
[6] https://mobile-wimax.jp/about/index.html
[7] https://archive.org/details/coastalhydraulic00huds
[8] http://postgis.net/
[9] http://mapserver.org/

TABLE I. COMPARISON AMONG MAPSERVER, POSTGIS AND GRASS GIS

Tool	Category	Functionality	Remarks
Map Server	Web Mapping engine	Thematic and the other maps generation and services	Useful tool for map services
Post GIS	RDBMS middle ware extension	Space retrievals extending data types to the PostgreSQL	Useful tool for geological retrieval services
Grass[10] GIS	Client based GIS software	Geological contents management	Useful tool for construction and edition of the contents
QGIS[11]	Improved all mighty GIS software	All the GIS functionality Python plug-in API	Latest version is 2.1.8[12]

PostGIS is one of the extensions of PostgreSQL. Therefore, it can be used for active database and is appropriate for customizing for tsunami warning. The required systems are as follows:

1) PostgreSQL[13]

This is a FOSS of relational database system with SQL : Structured Query Language. One of the options is PostGIS which is GIS extension of PostgreSQL. This includes a good interface to the GIS database with MapServer, Web mapping engine and Database access with PHP and MapScript

2) MapServer(PHP/MapScript)

This is PHP[14] based interface to database with PHP. Retrievals are then available through PHP Web page. When submit queries then the retrieved results are displayed from the database table.

3) MapScript[15]

Map engine allows displaying the retrieved results superimposing the other existing thematic maps. It consists of multiple layers. Raster and vector data of maps, meshed data and images through the PHP web browser.

It can be used with MapServer which allows display maps. Map engine allows display the retrieved results superimposing the other existing thematic maps. Multiple layers are available to show on the display. Raster and vector data of maps, meshed data and images can be seen on the PHP web browser.

MapServer international version (i18n) (i18n Version of Mapserver: Package) is used for displaying map data. MapServer 4.0.1 source code and patch for the international use is installed. PostGIS allows store the objects in concern to the GIS database. PostgtreSQL extension of PostGIS supports

[10] Geographic Resources Analysis Support System: GRASS, https://ja.wikipedia.org/wiki/GRASS_GIS
[11] https://ja.wikipedia.org/wiki/QGIS
[12] http://qgis.org/ja/site/forusers/visualchangelog218/index.html
[13] https://ja.wikipedia.org/wiki/PostgreSQL
[14] https://ja.wikipedia.org/wiki/PHP_(%E3%83%97%E3%83%AD%E3%82%B0%E3%83%A9%E3%83%9F%E3%83%B3%E3%82%B0%E8%A8%80%E8%AA%9E)
[15] http://www.mapserver.org/mapscript/

fundamental functions for analysis of GIS objects and spatial R-Tree index of the GiST base[16].

PostgreSQL can be downloaded from the following URL:

http://www.postgresql.org/.

PostGIS is source code tree of the PostgreSQL and can be installed by using the definition of installation process of the PostgreSQL. Also, PostGIS can be compiled with GNU C, GCC and/or ANSI C compiler. GNU Make, gmake and/or make can be used for making the PostGIS.

Geometry is a fundamental PostGIS spatial data type used to represent a feature in the Euclidean coordinate system. Therefore, PostGIS allows displaying geometric relations between the target event data onto an arbitrary map and the other satellite derived imagery data.

GNU make is the default version of make. Version can be confirmed with "make –v". Make file of PostGIS will not be processed properly when the different version of make is used. Proj4 is the library of the map projection conversion tools as one of the options of the PostGIS. Proj4 is available from the following URL; http://www.remotesensing.org/proj.

As for the utilization of Mapserver, Minnesota Mapserver is the internet Web mapping server and is compatible to the mapping server specification. Mapserver is available from the http://mapserver.gis.umn.edu/. Web Map specification of OpenGIS [17] is available from the following URL; http://www.opengis.org/techno/specs/01-047r2.pdf.

The sample application is derived from a real-world application that requires complex interactions between the database and the application server. There are three processing scenarios represented in the sample:

1) Making an HTTP call from Programing Language: PL/SQL to activate a Java Servlet

2) Using advanced queuing (AQ) to activate a Message-Driven Bean (MDB)

3) Using AQ to notify a Java client application of changes in the database.

This is key issue for the active database of the proposed tsunami warning system.

C. Warning and Evacuation Related Data and Information Transmissions

Mobile phone with 10km reachable WiMAX/WiMAX2: worldwide interoperability for microwave access of IEEE802.16 with 75 Mbps in maximum based on OFDM[18]: orthogonal frequency division multiplexing would be one of the most possible and considerable medias [9]. Warning information and comprehensive evacuation information with map and location attributes can be displayed onto WiMAX/WiMAX2 mobile phone. Java application seems to be the most appropriate programming language for WiMAX/WiMAX2.

[16] http://grokbase.com/t/postgresql/pgsql-sql/029bqmhnvk/r-tree-gist-or-b-tree-i-will-need-it
[17] http://www.sophia-it.com/content/Open+Geospatial+Consortium
[18] http://e-words.jp/w/OFDM.html

III. Example of the Ocean Related Dister Warning System

A. Preparation of Dataset

An attempt is conducted focusing mainly on ocean related disaster which corresponds to ocean related energy resources explorations as an example. Experimental results with significant wave height, ocean wind speed, geoids potential data which are derived from the altimeter onboard TOPEX/Poseidon [19] and Jason [20] satellites show potential usability on the customizing of PostGIS.

Create the database containing geoids, tides, ocean winds, wave height and so on from the NASA/JPL PODAAC [21] (Topex/Poseidon and Jason satellites data) by extracting the geo-referenced and time stamped data from the PODAAC. Access to the database through PHP and Mapscript then display the retrieval results of the appropriate ocean areas for the ocean energy exploration on the PHP web browser

B. Examples of Tsunami Related Data

There are some tsunami warning related research works [11]-[14]. Also, There are some GIS related research works as well [15]-[24].

Fig. 2 shows an example of the retrieved result of the significant wave height, sea level and wind speed in the Japanese vicinity for Jan 1 to Dec 31, 1998.

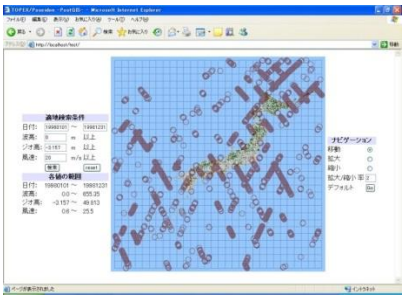


Fig. 2. An example of the retrieved result of the significant wave height, sea level and wind speed in the Japanese vicinity for Jan 1 to Dec 31, 1998. Translation, enlargement, and shrinking are available for the system.

The data are acquired from the NASA/JPL PODAAC of TOPEX/Poseidon data. Revisit cycle of the TOPEX/Poseidon satellite is 10 days so that it would not be enough data for the tsunami warning. It, however, is useful tool for ocean energy exploration. Appropriate location for the electricity power generation with ocean wind, tidal effect, and wave height can be found with the proposed free GIS system.

Also, hourly data stream of wind speed, Sea Surface Temperature: SST, and dynamic height as well as vertical profile of the sea water temperature and the other meteorological data provided from TOGA-TAO web site[22] of NOAA/PMEL/TAO project office[23] is attempted for PostGIS as an active database system.

[19] https://en.wikipedia.org/wiki/TOPEX/Poseidon
[20] https://sealevel.jpl.nasa.gov/missions/jason1/
[21] https://podaac.jpl.nasa.gov/
[22] http://toga-tao.de.websiteprofile.net/
[23] https://pmel.noaa.gov/

Fig. 3 shows dynamic height data at the nine different location in the TOGA-TAO ocean area at middle of the Pacific Ocean in the equatorial region as the data stream as of tsunami occurred on 26 December 2004 (marked with the red circle). After the tsunami hit, dynamic height raised a couple of centimeter and dropped a few cm after all. This is an indication of the tsunami measured at the 300 km apart from the earth quake occurred area.

Fig. 4 shows the wind speed, SST, and dynamic height at the specific location in the TOGA-TAO area before and after the tsunami hit Indonesia, Thailand, etc. occurred on 26 December 2004. Although just daily data are available at this time, if the sea level gages with mobile phone are situated at the appropriate areas, then sea level data are transmitted to the active database server site every minute. Thus, tsunami warning and evacuation information will be provided to the public, then the peoples who are living tsunami disaster is suspected areas can receive the information with the pagers and/or mobile phone with GIS capability.

There are some of required data for finding appropriate locations of ocean energy utilizing electric power generation plants. Namely,

1) Topex/Poseidon

Topex/Poseidon was launched on August 10 1992. This is the joint mission between U.S.A. and France. Specific features are the followings,

Microwave altimeter

Non-sun-synchronous

Inclination: 66°

Global coverage within 10 days

Fig. 5 shows Topex/Poseidon observes ocean surface along with its orbit.

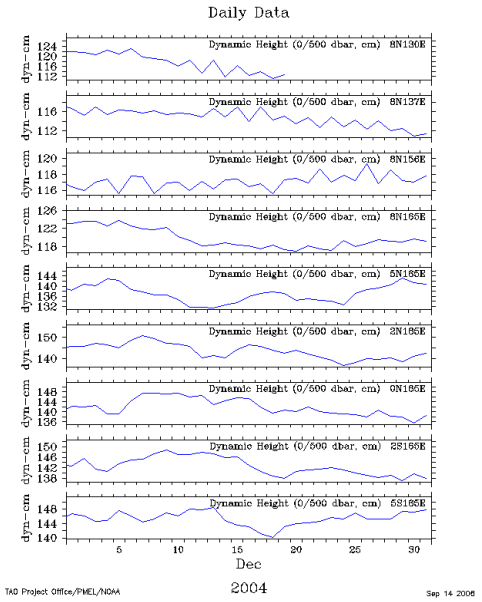


Fig. 3. Dynamic height at 9 different locations in TOGA-TAO area as of the tsunami hit Indonesia, Thailand, etc. occurred on 26 Dec. 2004.

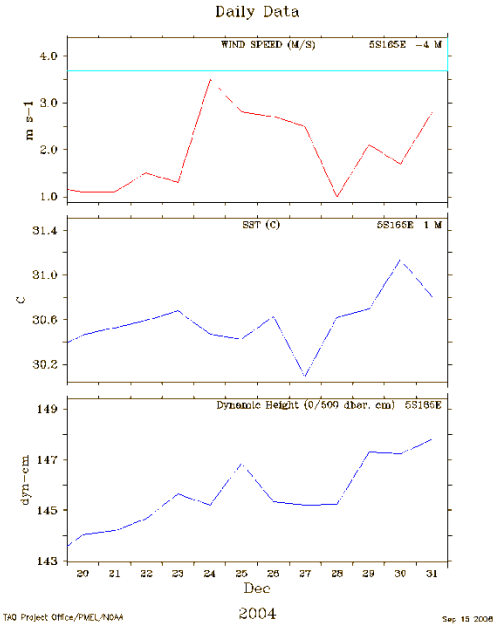


Fig. 4. Wind speed, SST, and dynamic height at the one of the location of TOGA-TAO before and after the tsunami hit.

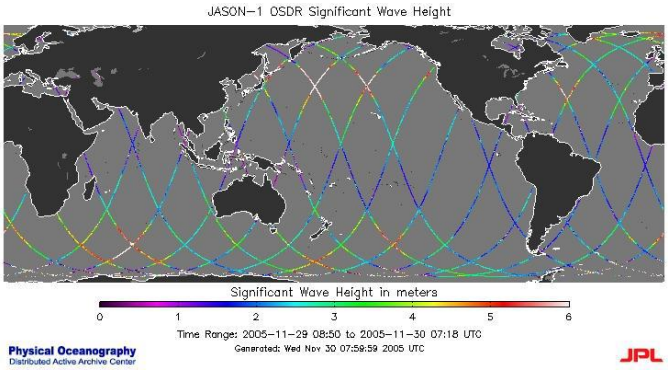


Fig. 5. Topex/Poseidon observes ocean surface along with its orbit.

2) Scatterometer

Ocean wind direction and speed can be estimated with scatterometer data. One of the scatterometers onboard satellites is SeaWinds [24] on Advanced Earth Observing Satellite: ADEOS-II[25]. This Scatterometer is onboard Quick scat satellite. SeaWinds on QuikSCAT Level 3 Daily Gridded Ocean Wind Vectors (JPL Version 2) data are available from the https://podaac.jpl.nasa.gov/dataset/QSCAT_LEVEL_3_V2.

Major specification of SeaWinds is shown in Table 2.

Fig. 6 shows geoid potential and wave height is estimated with the altimeter onboard Topex/Poseidon satellite. Follow-on project of Topex/Poseidon is Jason project. One of the product of Jason satellite based altimeter is shown in Fig. 7. This is a sea surface height anomaly observed from Jason-2 and Jason-3 measurements for 10 days, from 14 November 2017 to 24 November 2017. A large sea surface height anomaly is observed at the equatorial Pacific Ocean areas.

[24] http://winds.jpl.nasa.gov/missions/seawinds/
[25] http://en.wikipedia.org/wiki/ADEOS_II

TABLE II. MAJOR SPECIFICATION OF SEAWINDS

Radar:	13.4 gigahertz; 110-watt pulse at 189-hertz PRF
Antenna:	1-meter-diameter rotating dish producing 2 spot beams sweeping in a circular pattern
Mass:	200 kilograms
Power:	220 watts
Average Data Rate:	40 kilobits per second

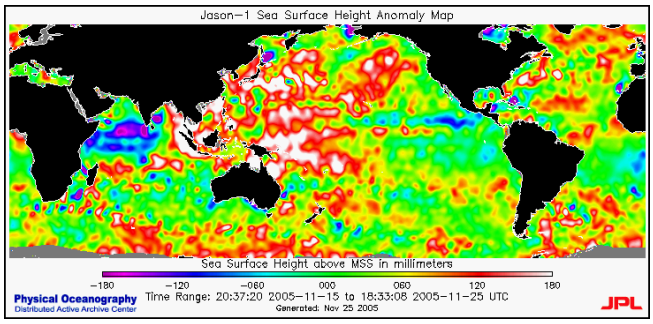


Fig. 6. Geoid potential and wave height is estimated with the altimeter onboard Topex/Poseidon satellite.

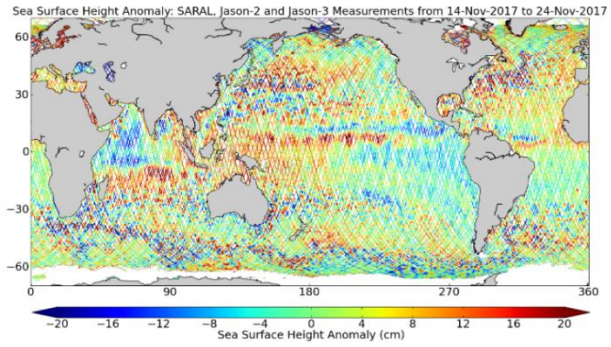


Fig. 7. Sea Surface Height Anomaly: SARAL, Jason-2 and Jason-3 Measurements from 14-Nov-2017 to 24-Nov-2017.

Along with satellite orbit, scatterometer observes ocean surface as shown in Fig. 8. Global coverage can be done. Then ocean wind direction and speed are estimated as shown in Fig. 9(a), (b).

Five days average of wind speed and vector wind is shown in Fig. 9(a) while five days average of dynamic height (21) and winds are shown in Fig. 9(b), respectively.

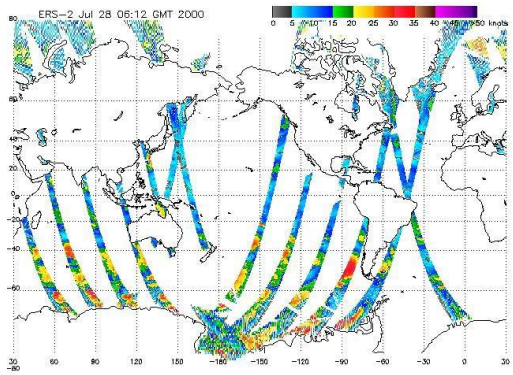
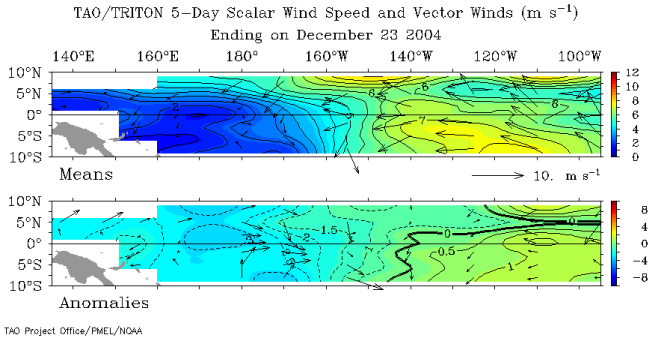
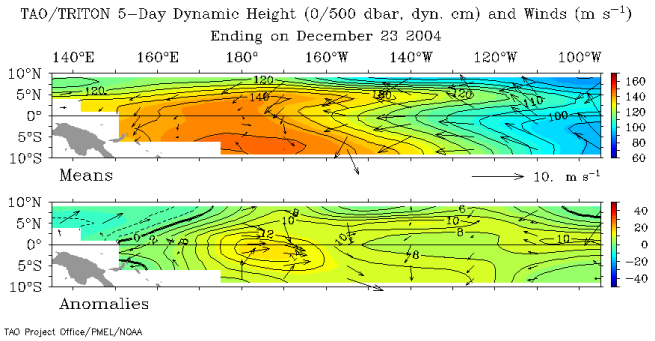


Fig. 8. Example of scatterometer observed ocean wind along with satellite orbit.



(a) Wind speed and vector winds



(b) Dynamic height and winds

Fig. 9. Example of estimated ocean wind direction and speed.

Thus, the most of required information, tidal situation, sea level height, geoid potential, ocean winds, and so on which is required to a Tsunami warning is gathered from the earth observation satellite, SeaWinds, Topex/Poseidon and MODIS onboard Terra and Aqua EOS satellites.

IV. CONCLUSION

A tsunami warning system based on active database system with satellite derived real-time data of tidal, significant wave height and ocean wind speed as well as assimilation data of sea level changes as one of the global risk management systems is proposed. Also, Geographic Information System: GIS with free open source software of PostGIS (extension of PostgreSQL) with Mapserver through the PHP is proposed for active database system. Also, it is confirmed that the most of functionalities of PostGIS (Submission of queries, retrievals of the appropriate data from the database, display the retrieved results on the PHP web browser). Furthermore, image processing and analysis are also available and can be applied to the retrieved data.

It is also found as the followings:

1) It is easy to customize the PostGIS (extension of PostgreSQL) with Mapserver through the PHP.

2) It is confirmed that the most of functionalities of PostGIS (Submitting of queries, retrievals of the appropriate data from the database, display the retrieved results on the PHP web browser).

3) Image processing and analysis are also available and can be applied to the retrieved data.

4) Most of required information, tidal situation, sea level height, geoid potential, ocean winds, and so on which is

required to a Tsunami warning is gathered from the earth observation satellite, SeaWinds, Topex/Poseidon and MODIS onboard Terra and Aqua EOS satellites.

Furthermore, it may say that the proposed tsunami warning and evacuation information provides system is recommendable.

Further experimental study is required to realize the proposed tsunami warning system in particular for practical use of the proposed tsunami warning system.

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REFERENCES

[1] Active Query Builder Standard VCL Edition V1.6

[2] Tsutomu TERADA, Masahiko TSUKAMOTO, Shijiro NISHIO, ``An Active Database System for Receiving Broadcast Data," Proc. of IASTED International Conference on Information Systems and Databases (ISDB 2002), pp. 122--128 (Sep. 2002).

[3] Jan Stankovic, Markus Neteler, Roberto Flor, Experimental Mobile Wireless GRASS based GIS for Handheld Computers running GNU/Linux, Proceedings of the Open Source GIS –GRASS users conference 2002-Trento,Italy.

[4] Spatial Data Infrastructure – Asia and Pacific Newsletter, SDI – AP, Newsletter Vol.2 No.2, February 2005

[5] http://handhelds.org - Support for Linux on handheld PC

[6] http://grass.itc.it/grasshandheld.html - Baby GRASS page

[7] http://www.wilmaproject.org - WILMA project pages

[8] Kohei Arai, Java based satellite image processing softwares, Morikita-Shuppan Co.Ltd., 2002.

[9] http://www.wimaxforum.org/

[10] Kohei Arai, FOSS GIS of PostGIS/MapServer and Java-based image processing and analysis software, Proc.ISPRS Commission IV, CATCON-4, 2000.

[11] K.Arai, Relation between sensor data collection and analysis and knowledgebase for tsunami warning system, Proc. of the 1st International Symposium on Universal Communication, Session #8, Knowledge processing of multimedia information, Kyoto, 2007.

[12] Kohei Arai, ICT technology for disaster mitigation,-Tsunami warning system-, Proceedings of the 1st International Workshop on Knowledge Cluster Systems, 2007.

[13] Kohei Arai, Data collection and active database for tsunami warning system, Proceedings of the 1st International Workshop on Knowledge Cluster Systems, 2007.

[14] Kohei Arai, Communication links and evacuation/navigation information services for tsunami warning system, Proceedings of the 1st International Workshop on Knowledge Cluster Systems, 2007.

[15] K.Arai, Free Open Source Software: FOSS based GIS for spatial retrievals of appropriate locations for ocean energy utilizing electric power generation plants, International Journal of Advanced Computer Science and Applications, 3, 9, 95-99, 2012.

[16] Kohei Arai, Cell based GIS as cellular automata for disaster spreading predictions and required data systems, Advanced Publication, Data Science Journal, Vol.12, WDS 154-158, 2013.

[17] K.Arai, Four Dimensional GIS and Its Application to Disaster Monitoring with Satellite Remote Sensing Data, Proceedings of the Conference on GIS and Application of Remote Sensing to Disaster Management, 132-137(1997)

[18] Kohei Arai, Open GIS with spatial and temporal retrievals as well as assimilation functionality, Proceedings of the Asia Pacific Advanced Network Natural Resource Workshop, Utilization of Earthy Observation Satellite-Digital Asia Special Session 1,p8, 2003.

[19] Kohei Arai, Geographic information system: GIS based on neural network for appropriate parameter estimation of geophysical retrieval equations with satellite remote sensing data, Proceedings of the IEEE Geoscience and Remote Sensing, PID 220128, 2006.

[20] Kohei Arai, Space and time retrieval of tide wind speed and wave height with altimeters onboard satellites based on Post-GIS system, Proceedings of the Renewable Energy Resources Symposium, 00548, 2006.

[21] Kohei Arai, Chapter 4: A sea surface temperature estimation method for ocean areas and seasons using a GIS as Neural Network, Proceeding of the Marine Science, 9, 43-51, 2008.

[22] Kohei Arai, Cellular automata approach for disaster propagation prediction and required data system in GIS representations, Proceedings of the 1st ICSU/WDS Conference - Global Data for Global Science, 2011.

[23] K.Arai, Cell based GIS as Cellular Automata for disaster spreading prediction and required data systems, CODATA Data Science Journal, 137-141, 2012.

[24] Ari Sandhyavitri, Fajar Restuhadi, Rudianda Sulainan, K.Arai, Sigit Sutikno, Assessment of Mangrove Carbone Stock Based on Remote Sensing (RS) Geographic Information System (GIS) and Ground Check (GC) Methods in Indragiri Hilir Indonesia, Proceeddings of the ICCOE Conference, 2015.

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