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EARTHQUAKE EARLY WARNING AT OCEAN NETWORKS CANADA: THE WARN PROJECT

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ABSTRACT: Ocean Networks Canada (ONC) operates cabled ocean observatories off the coast of British Columbia to support research and operational oceanography. Recently, ONC has focused its cable technology and data management software to deliver an integrated coastal information system that provides seismic monitoring data to researchers and will deliver early geo-hazard (earthquake and tsunami) warning to subscribed clients. ONC's cabled seismic network has the unique advantage of being located offshore on either side of the surface expression of the Cascadia Subduction Zone. This represents a distinct advantage to seismic monitoring and earthquake early warning. The Web-enabled Awareness Research Network (WARN), part of ONC "Oceans 2.0" data management system, performs the early detection of tsunami and earthquakes. WARN implements fast event detection and correlation from the data streams of networked seismic sensors distributed on-land and offshore. Using the Common Alert Protocol (CAP), WARN delivers alerts to clients interested in programming a reaction to the alerts.This paper focuses on the earthquake early warning capabilities of WARN. It describes the seismic sensors and their distribution, the P-wave detection algorithms selected and the overall architecture of the system. It further overviews the plan to demonstrate the functionality of earthquake early warning technology during the 2015 Great BC ShakeOut earthquake drill. In this systems test, clients will receive earthquake location and magnitude data based on P-wave analysis from networked sensors and models implemented on the client side will estimate the time of S-wave arrival and the shaking intensity at the client's location. If shaking is estimated to exceed a pre-established threshold, automated systems will mitigate damage..

1. Introduction

Ocean Networks Canada (ONC — see http://oceannetworks.ca/) is a not-for-profit organization that manages the NEPTUNE (Barnes 2007), VENUS (Dewey 2007) and Cambridge Bay (Hofmann 2013) cabled ocean observatories on behalf of the University of Victoria, extending the Internet underwater all the way to a vast array of instruments and sensors (Pirenne 2015). Those sensors are provided with power and communication capabilities, ensuring 24/7 operations, a high data rate and quasi real-time data. The User Engagement Division of ONC is in charge of the development and maintenance of the Organization's data management and archiving system, known as "Oceans 2.0" (Pirenne 2012). We have been successful in setting up software systems that acquire data from large sensor networks, archive them and make them available to a varied audience of scientists, the public and various government and non-governmental agencies.

Data from over 200 currently online instruments are available from Oceans 2.0 with no proprietary period. Data can be previewed through a number of web-based tools such as video viewers and plotting utilities and can be downloaded through search interfaces and web services. Data are available in a variety of formats and can be subjected to a number of pre-processing steps on behalf of the user. Formats are often specific to the scientific disciplines of our users. Oceans 2.0 has deployed a fairly complete instrument vs. data products/data formats matrix to translate and deliver data to suit user needs.

WARN, the web-enabled awareness research network leverages the capabilities of ONC's sensor networks and data management system and is expanding them by adding new derived "data products" that address key societal concerns related to geohazards. WARN forms the event detection and notification system that is part of ONC's Smart Oceans™ initiative. Smart Oceans BC, in particular is specifically adding observational assets along the British Columbia coast to serve new stakeholders such as government, industry and coastal margin users, in the areas of geohazards among others. See the map of Smart Oceans™ in Figure 1. The development of WARN was made possible through funding from CANARIE, in the context of their Network Enabled Platform program. (See http://canarie.ca/software/platforms/).

Fig. 1: The Ocean Networks Canada Smart Oceans™ map of British Columbia and the location of many of the sensors necessary to support geohazard detection.

In this paper, we highlight some of WARN's functions and its overall architecture. Figure 2 illustrate the place of WARN within the set of tools and products based on Oceans 2.0.

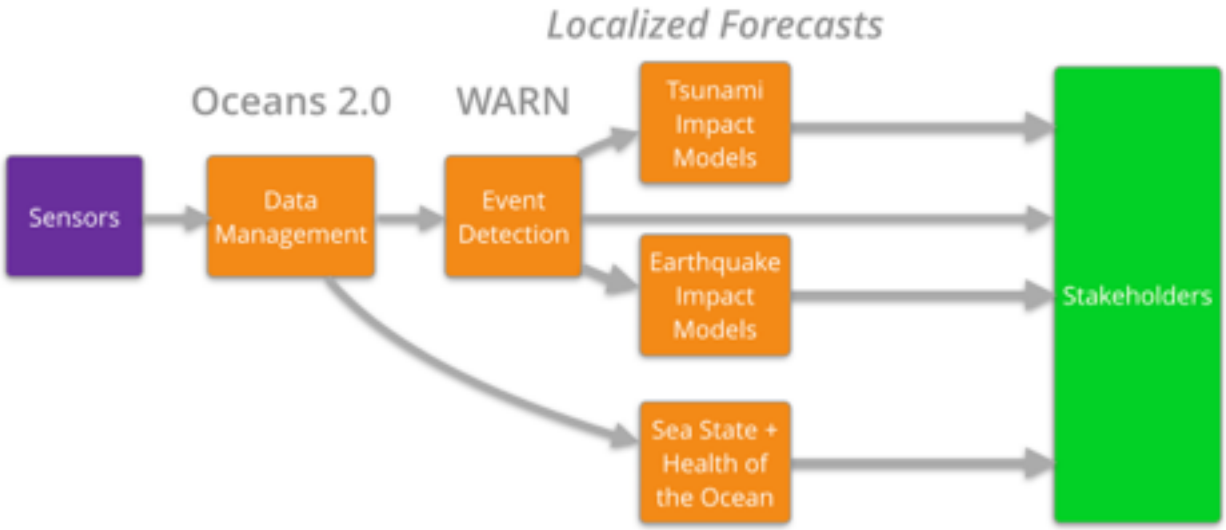

Figure 2: The WARN system in the context of Ocean Networks Canada's Oceans 2.0 system.

2. How WARN works

The WARN module within Oceans 2.0 provides subscribers with early notifications of **regional scale** geohazards such as tsunamis and earthquakes as part of the Ocean Networks Canada's Smart Oceans BC initiative. WARN does not try to implement local detection and alerting but rather, thanks to sensors located a few hundred kilometres from subscribers, aims at providing tens of minutes of warning for tsunamis and of the order of one minute for earthquakes. WARN utilizes the Oceans 2.0 data acquisition infrastructure while incorporating some new instruments and new event detection algorithms. Tsunami detection uses data from pressure sensors such as the existing Bottom Pressure Recorders (BPR) for far-field tsunamis and a high-frequency coastal radar system for near-field events. Earthquake detection uses accelerometers that allow for P-wave detection. An number of them were deployed in late 2014 both on land and underwater. They will be upgraded in 2015 and 2016 with more sensitive instruments. While WARN was implemented as a research/prototype with limited sensors and select early adopters for now, it is being designed to be expandable to greater numbers and types of instruments and subscribers.

WARN receives instrument data, and returns intrinsic event data such as tsunami detection time, wave height and direction, and earthquake magnitude and epicentre, which can be used in impact assessments by subscribers. Subscribers are notified by either e-mail (generally only useful for test purposes) or direct server-to-server call. Indeed, as there is little time for reaction, only computer-to-computer interaction with no human in the middle makes sense in most cases, particularly for earthquake notification. In the rest of this paper, we will focus solely on the earthquake detection aspects of WARN.

Earthquake detection

Earthquake detection is performed using a number of accelerometers located on land and on the seafloor offshore Vancouver Island. Accelerometers normally only output a characteristic amplitude value, the Japanese Meteorological Agency's (JMA — see Kamigaichi 2004) instrumental intensity, but we are not using it at this point. Instead, WARN's driver software, which runs on a computer co-located with the accelerometer, analyzes the accelerometer data on all three axes and looks for the signature of a "P-wave", which is the initial compression wave emanating from the earthquake. This P-wave does not cause damage but travels much faster than the "S-wave" that therefore comes later and is at the source of potential damage. If a P-wave is detected, the driver outputs the time of detection of the P-wave. Subsequently the driver analyzes the first few seconds of motion and determines the maximum displacement of the vertical component of the acceleration (Pd), and the maximum period of the vertical component (Tau). The Pd and Tau values are then sent out from the driver computer to the central Oceans 2.0 data centre, located at the University of Victoria for further processing.

The P-wave time, Pd, and Tau are analyzed by two algorithms to determine the epicentre and time of origin, and two different algorithms to determine the magnitude (the JMA algorithm is not used at this time) - see Figure 3 below.

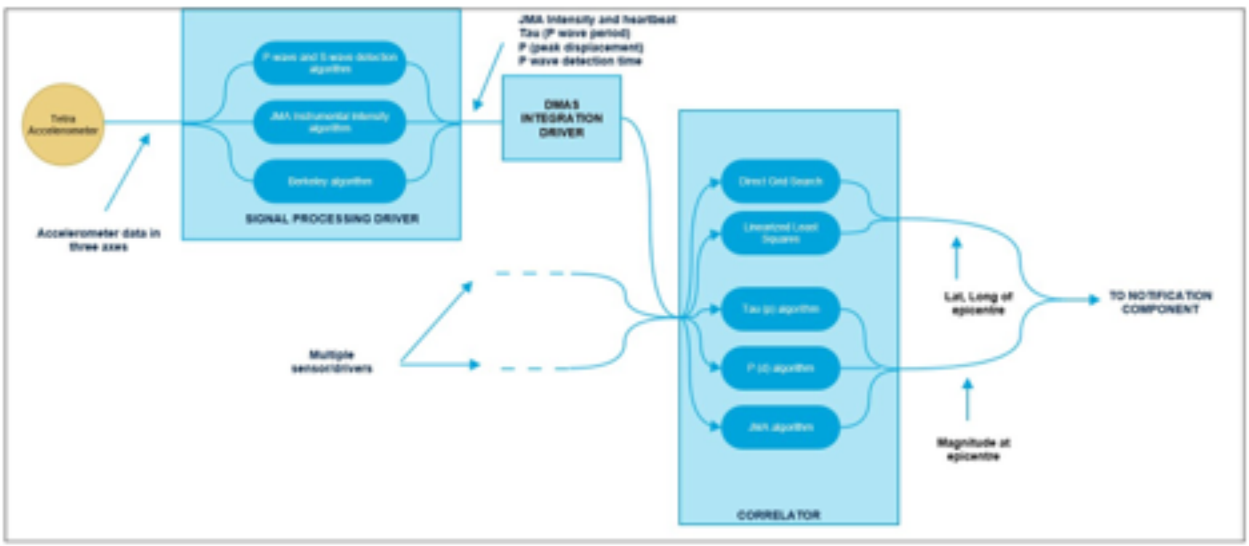

Figure 3: WARN Earthquake detection: overall concept.

An epicentre can be determined provided at least three accelerometers have reported a P-wave detection. The P-wave detection times are analyzed using a direct grid search algorithm where a pre-defined region is divided into cells of equal size. Each cell is analyzed by triangulation, knowing the location of the centre of the cell and the relative detection times of the P-wave at each of the sensors, plus the location of the sensors. The cells are first analyzed on a coarse grid basis to determine the cell with the highest probability of being the epicentre of the earthquake. This cell is then further analyzed on a fine grid using the same method. In the end the centre of the most probable fine grid cell is used as the epicentre latitude and longitude, with a resolution of +/- 0.05 degrees. If the quality of the solution is considered high enough, an earthquake is declared by the Earthquake Correlator and the results are passed to the Event Notification component.

Further detection of P-wave arrival by other accelerometers in the network trigger the recalculation and the Direct Grid Search runs again. In addition another algorithm called Linearized Least Squares also analyzes the subsequent P-wave arrival times. Knowing the distance from the epicentre to the sensors, the time of origin of the earthquake can be determined.

The magnitude of the earthquake is estimated using two methods. One method compares the Tau (period) values reported by the accelerometers, which is expected to be the same at all sensors. The magnitude is proportional to the Tau on a logarithmic scale. The other method uses the Pd or maximum vertical acceleration reported by each of the sensors. The Pd is attenuated by the distance to the sensor on a logarithmic scale. So after factoring in the attenuation due to distance, the magnitude is logarithmically proportional to the Pd.

The epicentre coordinates, time of origin, and magnitude are passed to the Event Notification software.

Event Notification

The Event Notification component of WARN allows for the definition and activation of events, the manual test of events, and lets individuals and organizations subscribe to them and decide how they wish to be notified. The server notification method is the preferred way to ensure rapid response. In this case, ONC's Oceans 2.0 directly calls a specific URL on the subscriber's computer. The URL (or web service), upon invocation, will then run local software that will:

1. calculate the possible impact of the geohazard on this subscriber's assets, taking into account their distance to the epicentre and their sensitivity to the calculated residual shaking at that distance
2. determine a reaction to be executed (such as turning off valves, slowing down trains, …) given pre-determined and pre-programmed scenarios

3. Plans moving forward

At the time of this writing, the Software Engineering department of Ocean Networks Canada is completing the software aspects of the WARN project and performing tests to verify the concepts and their implementation. In parallel, new, very sensitive sensors are going to be deployed on land. Underwater installations of more capable sensors will occur in 2016. The current proof of concept that WARN represents is based on a number of sensors installed on the north-west side of Vancouver Island and off the coast on the NEPTUNE observatory. It establishes the necessary capabilities to monitor and notify the surrounding regions of seismic events occurring at or near the Nootka fault line, where a few small to medium-size earthquakes are expected on an annual basis. Beyond this proof of concept, ONC is planning to expand the network to cover most of Vancouver Island and to therefore monitor the northern end of the Cascadia subduction zone with the goal of providing early warning to the urban centres of Vancouver and Victoria.

In parallel and in the context of the Smart Oceans BC programme, ONC is anticipating the installation of a network of sensors on the north coast of British Columbia to establish a similar notification system for geohazards that would threaten the regions of Prince Rupert, Kitimat, etc. where a significant increase in industrial activity is expected in the coming years.

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