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Recent development of airborne surveys of the Earth

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This presentation summarizes the recent development of airborne surveys and monitoring of the Earth.

Keywords: airborne geophysics, airborne gravity survey, airborne magnetic survey, airborne electromagnetic survey, airborne radiometric survey, airborne thermal infrared survey

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Observation at Sakurajima volcano using an unmanned autonomous helicopter

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Observations in the vicinity of summit area of active volcanoes are important in understanding volcanic processes. However, it is challenging to install observation sensors near the active vent because of the danger of sudden eruptions, and thus the summit area of active volcanoes are often left blank from the observational point of view. We are developing a risk-free observation system based on an unmanned autonomous helicopter (UAV) combined with various types of observation devices. The UAV has been already used for the aeromagnetic surveys in Izu-Oshima, and succeeded in detecting fine scale geomagnetic anomalies. In addition to the aeromagnetic survey, we aim at developing various types of volcano-observation tools based on the UAV such as installing seismometers and GPS modules, sampling volcanic ash in the vicinity of active vents, and obtaining both infrared and visible images from onboard cameras. In this presentation, we will present an outlines of the installation of seismic modules at Sakurajima volcano, Japan conducted in fall of 2009 and 2010.

We used the UAV, model RMAX-G1 developed by Yamaha-Motor Co., Ltd. The payload of the helicopter is approximately 10kg, including the fuel and attached equipments. The autonomous aviation is available within 5km from the base station with meter accuracy using kinematic-differential GPS. This high positional accuracy makes it possible to conduct repeated observation at exactly the same place. Real-time images taken from the onboard cameras are transmitted to the base station. This facility is a great advantage in remote installation of sensors.

We developed an earthquake observation module (EOM) and a winch system both are designed exclusively for the UAV. Since the payload of the helicopter includes not only the weight of the EOM but also the weight of the onboard winch, onboard camera, and fuel, we had to limit the EOM's weight around 5kg. In order to realize such light weight, we had to newly develop light-weight solar panels. The EOM is carried by the helicopter to just above the target point for installation, being hanged at the tip of the wire of the onboard winch. Then, by sending out the wire gradually from the winch, the EOM is dropped slowly and is installed on the ground without strong shock. The EOM is solar powered, and is equipped with GPS for timing. Data are transmitted over the cellular-phone network. Since it is also difficult to level the sensors, a triaxial accelerometer is adopted as a seismic sensor.

Sakurajima is one of the most active volcanoes in Japan. Since the reopening of the Showa crater at the eastern flank in 2006, eruptions continue at the Showa crater, and the recent annual number of explosive eruptions is record-breaking. Entering the area within 2 km from the summit craters is prohibited, and thus there is no observation station in the restricted area. Seismic sensors in this area will significantly improve the data quality. From November 2nd to 12th in 2009 and 2010, we installed the EOMs in the summit area of Sakurajima within 2km from the active vent. We carefully investigated geographical maps and high resolution aerial photographs beforehand in order to decide potential target positions for installation of EOMs. In the experiment in 2009, we could successfully install three modules at the planned positions. In the experiment in 2010, we not only could install EOMs at 4 places, but also could retrieve three EOMs installed in the previous year. Although the EOMs installed in 2009 could not work properly due to trouble of the EOMs main board, the EOMs installed in 2010 are still arrive and are sending seismic signals at the time of this abstract submission. Although the recorded waveforms of the explosive eruptions are contaminated by the modules mechanical resonance noise above 30 Hz or more, waveforms in general are good in the frequency band lower than that frequency.

Keywords: Unmanned helicopter, volcano observation

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A Basic for Gravity Measurement Performance of Simple Gravimeter Using a Force-Balanced-Type Accelerometer on a Carrier

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The gravity survey is applied often to model a ground structure. Forthis purpose, a spring-type relative gravimeter is usually used. Thoughthis type of gravimeter can provide very accurate data, it is veryexpensive and difficult to handle. In the engineering field, especially,for the estimation of earthquake ground motion, a model of groundstructure is needed for large area. This means that a simple and inexpensive sensor to measure the gravity is required. For this, we began to develop a new gravimeter using a force-balanced-type accelerometer. In this study, we examine basic performance of same sensors. Firstly, we develop a preliminary system and calibrate it. Then, a simple measurements was carried out using a Ferris wheel, and some other carrieres.

Keywords: gravity survey, force-balanced-type accelerometer, mobile carrier, Independent Component Analysis

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The use of Geonet combined with RTK-GPS on board the air/sea moving platform and its results

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In gravity measurement on board aeroplane or ship the accuracy of positioning has as significant effect on the accuracy of gravity as the sensitivity and stability of gravity sensor and precision of levelling. In gravity measurement using aeroplane or ship the GPS receiver installed on board the moving vehicle is compared with the GPS receiver installed on land base station, and interferometric positioning is conducted using the paired signals. By this method we can obtain the position of the moving platform with the cm order accuracy. However, this sort of positioning is likely to be subject to the refraction of radio wave from satellites so that the interferometric positioning yields large errors as the distance of base line increases. The order of magnitude of such effect is about 1cm as long as the base length is shorter than 10km. If it is longer than 50km, the error reaches 10cm. In 2009, however, we experienced the least ionospheric refraction case when the error of positioning was smaller than 5cm whereas the base length was larger than 50km. We knew later that in 2009 the solar activity was minimum so that the effect from the ionosphere was minimum.

In case of gravity measurement on moving vessels it is something to build a base station over the area of survey. It may be necessary to keep a person at each GPS base station, which is a work not light to execute.

From January to March we got a chance to get on board the Shioji-Maru belonging to TUMST. We installed two GPS receivers on this ship, and measured the position of the ship. These GPS receivers are compared to GEONET receivers distributed near-by. Since Geonet bases are located

at about 10km spacings it is expected that a few cm accuracy in positioning is reached and demonstrated by our present researches.

Keywords: Positioning of cm accuracy, RTK-GPS, Accuracy of positioning of moving platform, GEONET, Base distance, Accuracy of gravity measurement

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Magnetic anomaly change of Usu Volcano 2000-2010 detected by repeated aeromagnetic surveys

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Aeromagnetic survey is expected to contribute to the elucidation of the volcanic structure and the change of its activity. However, the track lines of repeated surveys cannot be the same, and the inspection to the repeatability and the spatial alias effect of magnetic anomaly pattern is quite important to acquire valid information of the activity. To overcome this difficulty, we applied the generalized mis-tie control method (Nakatsuka and Okuma, 2006; Nakatsuka et al., 2009).

Usu Volcano 2010 aeromagnetic survey was conducted by the Usu Volcano Aeromagnetic Study Group, in September, 2010 (Hashimoto et al., 2011). The existing reference data is the survey by the Geological Survey of Japan in June 2000 (Okuma et al., 2003, 2010). Both data were processed together with the generalized mis-tie control method to yield total-force magnetic anomaly change between two epochs. The result revealed increases of magnetic force at Nishiyama-Kompira crater activity areas, the area of Gin-numa crater, and Showa-shinzan dome, and a relative decrease zone along northern somma. The comparison of the result with other studies' observation and the interpretation is to be presented in another paper (Hashimoto et al., 2011).

Although the track lines were fixed by the post-flight differential process of GPS system in both surveys, the altitude fix in 2000 survey might not be accurate enough because of insufficient accuracy signal from a few satellites among GPS satellites. As 2000 survey flights were equipped with a radio-altimeter, the altitudes difference between GPS and radio-altimeter data was examined in detail, with the help of Volcanic DEM (10m mesh) by the Geographical Survey Institute. Considering that the data of radio-altimeter reflect artificial buildings and constructions, the slant radio-wave reflection from sideward topography, and the existence of thick surface vegetation, the GPS altitude data is proven to be generally well determined. Nevertheless, GPS altitude in 2000 survey may have occasional shift of 20-30 m, and also the unreasonable difference ($<$ 10m) against radio-altimeter over the Lake Toya was revealed. As a whole the altitude accuracy of 2000 survey data is not minimal enough. If we consider this altitude accuracy, finer variations in the results above should be carefully interpreted, although the principal characteristics of the analysis results above are still reliable.

Keywords: Usu Volcano, aeromagnetic survey, magnetic anomaly change, generalized mis-tie control, volcanic activity, helicopter

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Accuracy improvement of tunnel geological features evaluation by helicopter-borne EM and magnetic survey

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1. Introduction
For long tunnels, however, surveys must cover a wide range of areas, placing a limit on the feasible improvement in accuracy, as adequately grasping the geological conditions of the entire tunnel ground as well as depth properties incur significant labor and costs. Geophysical explorations making use of helicopters are applied in civil engineering geological fields, such as long tunnels and of large scale landslides, have recently been on the increase. This method enables the simultaneous conduction of more than one exploration at a time with electromagnetic soundings and magnetic prospecting from the air. Capable of rapidly and broadly measuring the characteristic values of the underground, this method allows the gathering of three-dimensional geological information.

2. Outline and Method
The authors were carried out HEM (helicopter-borne electromagnetic method) and the HMS (helicopter-borne magnetic survey) on a planned mountain tunnel with a total length of 4.1 km and 0.9 km long tunnel in the accretionary complex areas of Hokkaido, Japan. Records and survey results of constructed tunnels were also examined. Moreover, the pilot boring core, which had been conducted at all lines of the tunnel, was analyzed, shedding light on lithofacies distributed throughout the aforementioned areas. In the area surrounding the survey site, the Nikoro Group of the Tokoro belt is distributed. The Nikoro Group mainly consists of greenstone, pyroclastic sedimentary rock and hyaloclastite, and is mixed with pillow lava, chert and limestone. Many faults are formed in the area around the survey site due to tectonic movements at the time of formation of the accretionary complex and after that. The authors describe the feasibility and effectiveness of helicopter borne surveys tunnel construction to detect the distribution of geological property in the accretionary complex area by comparing them with other geological data and observation results.

3. Results
As the results, apparent electrical resistivity by HEM, it was found to reflect the lithofacies and the degree of weathering, deterioration and frequency of shear and fracture of the underground. According to data of seismic refraction, it was confirmed that the low velocity layer corresponded to a low apparent electrical resistivity part. Several low resistivity zones, mottled or relatively steep gradient parts of resistivity were recognized. These area or zones were correlated with actual lithofacies and actual geotechnical problems encountered by the tunnel excavation. As for the magnetic intensity by HMS, it was showed high value in basalt area, and low value in hyaloclastite area respectively. These tendencies correspond to the distribution of geological property observed by horizontal pilot boring core ahead of the tunnel excavation. Thus, the distribution of geological property will be indicated not only by the apparent electrical resistivity but also by the magnetic intensity. By these two combinations, the geotechnical condition is estimated briefly without decreasing its accuracy.

Keywords: helicopter-borne EM, helicopter-borne magnetic survey, tunnel

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Response characteristics of GREATEM system considering a half-space model

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ABSTRACT
The GRounded Electrical source Airborne Transient EM (GREATEM) system employs a cable transmitter on the ground and an airborne receiver coil flown below a helicopter. In comparison to other helicopter borne TEM (heli-TEM)systems, the main advantage of the GREATEM system is that it does not fly a large transmitter loop that makes the payload heavier and the survey logistics more rigorous, and expensive. The possibility to apply a large source moment (long cable and high amplitude current) facilitates recording good S/N ratios even at relatively higher flight altitudes(>100m). Also, the long duration pulses (1 cycle lasting 1.6 sec) and all time measurements make it possible to obtain reliable late time (> 20 msec) signals to probe greater depths. We have studied the response characteristics of the GREATEM system considering a half-space model.

The resistivity of the half-space is varied over a wide range to represent various types of geological terrains and rock types. The study reveals the range of resistivity values (resistivity aperture) which can be resolved well by the GREATEM system. The influence of varying the flight height and the distance of the source cable is also studied. Due to the deployment of grounded source, the GREATEM survey area is confined to a few tens of square km in the vicinity of the source cable. However, comparisons with other heli-TEM and ground TEM systems clearly bring out several advantages of the GREATEM system.

Keywords: Helicopter borne TEM (Heli-TEM), Deep penetration Heli-TEM, Grounded source Heli-TEM, Helicopter borne LOTEM

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Applicability of airborne electromagnetics to coastal areas: Kujyukuri case

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Understanding hydrogeological character in coastal areas is an issue of paramount importance considering that most people live and work while catastrophic natural disasters occasionally happen. It is also important to delineate the distribution of fresh and saline water to maintain sustainable development in coastal areas and also for siting of geological disposal of nuclear wastes. Nonetheless limited information has been acquired to this day for the lack of suitable survey method. Airborne electromagnetics (AEM) is a method to survey underground by means of electrical resistivity. It has a merit to survey both land and sea simultaneously. While conventional AEM can reveal resistivity only to a depth of ~300 m on land, we succeeded to increase the survey depth to ~1000 m by employing grounded electrical source airborne transient electromagnetics, or GREATEM. Here, we applied GREATEM to a coastal area for the first time. The Kujyukuri coastal plain, Boso Peninsula, was selected for our study. This area is suitable because shallow seawater develops and enough resistivity data are available by grounded electromagnetic survey on land, electrical resistivity measurements at sea, and borehole logging. As a result, it was found that GREATEM can reveal resistivity structure in the coastal area to a depth of 300-350 m within ~1 km offshore.

Keywords: Airborne electromagnetics, Coastal area, Kujyukuri