Changing earth as shown by gravity

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The earth is subject to universal gravitation, which in Sapporo is approximately 9.80 meter per square second (980 gal). Slight gravitational differences from place to place are referred to as gravity anomalies, and have long been studied as an important clue toward understanding the earth's interior. Hokkaido University also has precise gravimeters based on spring-scale principles, and these have been used for purposes such as studying volcanic subsurface structures.

In 2002, artificial satellites named Gravity Recovery and Climate Experiment (GRACE), designed to measure gravity, were launched, making it possible to pinpoint even the slightest temporal differences in gravity. If a gravimeter is taken out into space, gravity cannot be measured in the weightless conditions within satellites. However, artificial satellites repeat acceleration and deceleration due to the unevenness of gravity while orbiting the earth. GRACE is a groundbreaking system that measures the entire gravitational field of the earth (or in technical terms, determines the shape of the earth's equipotential surface, known as the geoid) only in a month by measuring slight changes in the distance between the twin satellites. The temporal gravity changes obtained on various scales by the satellites show new aspects of the earth (Fig. 1).

Looking at changes in gravity in North America (Fig. 2), the reduction of mountain glaciers in southern Alaska as well as continental ice sheets in southern Greenland caused by global warming is manifest in the decreased levels of gravity. The gravitational force decreases by an amount equivalent to the attractive force of the ice that disappears. Conversely, gravity is increasing in northern Canada, where the last glacial period was many thousands of years ago. The ice sheets that blanketed the nation thawed, and the earth's crust that had been beneath the ice sheets has slowly been upheaving. The gravitational force increases by the increase in the amount of rock. If all the ice in Greenland thaws in the future, the same will happen. Surprisingly, gravity does not change if ice thaws in the Arctic Ocean, a habitat of polar bears. This is because the ice simply turns to water,

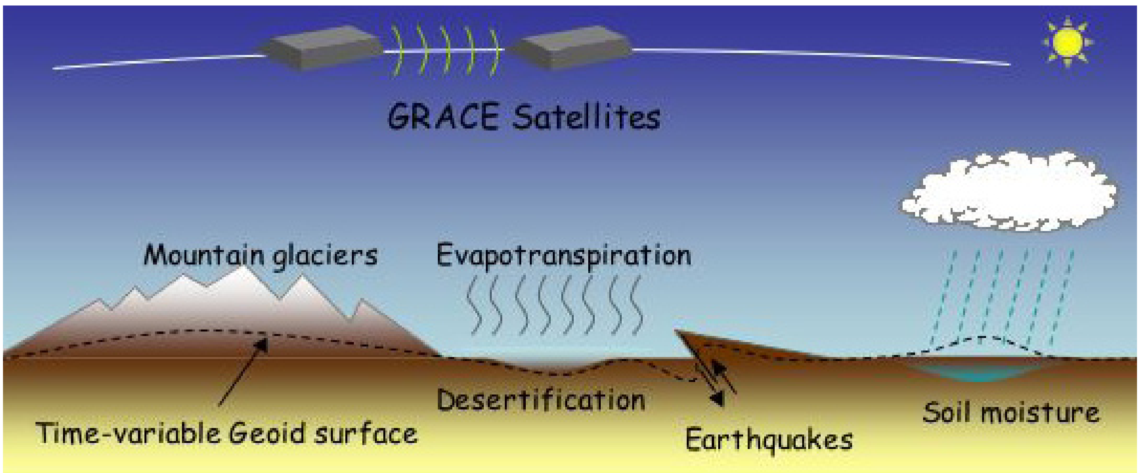

Fig. 1 GRACE is a system to detect surplus and deficient masses on the earth's surface based on changes in the distance between the twin satellites. Temporal mass changes enable the measurement of ice sheet reduction caused by global warming and the accompanying ground uplift, as well as soil moisture movement, mantle expansion/contraction by earthquakes, etc.

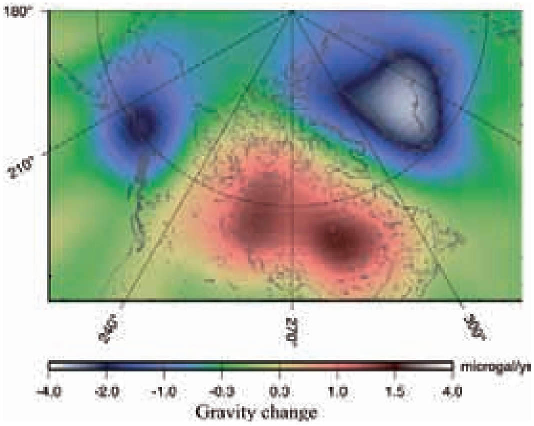

Fig. 2 Gravity changes around North America from 2003 to 2007 as seen by the GRACE satellites. Prominent changes are marked in blue (indicating gravity decreases caused by continued ice thaw) and red (showing gravity increases following ground uplift where ice sheets have thawed in the past).

and the quantity of matter remains unchanged. Once land-based ice thaws and flows into the sea, however, terrestrial gravity decreases (in turn, ocean gravity should also increase, but since the change is spread thinly over a large area, it is difficult to see). These fluctuations amount to several microgals annually, representing a change of around one billionth of the earth's gravity.

Temporary climate change also appears in the form of gravity change. El Niño and its counterpart La Niña used to be considered as phenomena causing abnormal seawater temperatures off Peru, but are now known to be global phenomena affecting the worldwide climate. Among other manifestations, rainfall patterns are significantly affected, causing droughts and torrential rains in various places around the world. When torrential rains fall over the sea, the water flows away and does not cause gravity to increase. If they fall on land, however, soil moisture rises and gravity temporarily increases. A La Niña episode occurred from 2005 autumn to 2006 spring, and Fig. 3 shows the gravity deviation in February 2006 from the reference value. A gravity decrease caused by droughts in East Africa and an increase in equatorial South America are clearly shown. With the El Niño episode that occurred one year later, an almost opposite pattern of gravity change was observed.

It was theoretically predicted that gravity would change slightly before and after major earthquakes, and GRACE created a buzz when it first detected a change of approximately 10 microgals at the time of the Sumatra Earthquake in 2004. An earthquake is a phenomenon in which underground faults slip, and the subsequent expansion and contraction of the earth's crust and upper mantle cause changes in gravity.

As such, it has become possible to look at various phenomena in the context of time-variable gravity field. However, the current GRACE system is rather short sighted, and can see only objects that are more than 500 km wide. Holding the key to its precision are the accuracy of inter-satellite distance measurements and the sophistication of the accelerometer that corrects atmospheric drag, which causes the satellites to decelerate regardless of gravity. The GRACE satellites were launched jointly by the U.S. and Germany, and there are moves for Japan to launch its own satellite using domestic technology.

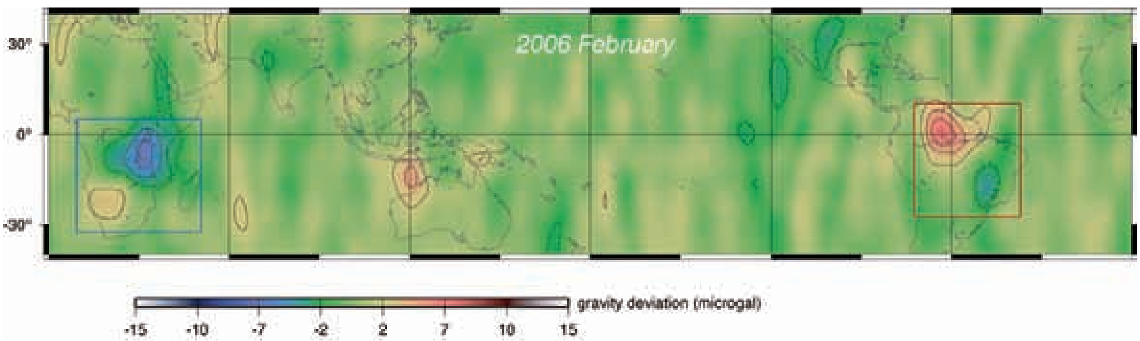

Fig. 3 Differences in gravity from the standard value as of February 2006. Abnormal rainfall caused by the La Niña episode that began in late 2005 is shown in the form of gravity changes in Africa and South America through abnormalities in the water content of the soil.