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Climate and Tectonic Changes in the Ocean Around New Zealand

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Many countries have recognized climate change due to human activities as one of the most critical issues facing the modern world. However, validating predictive models of the potential anthropogenic impact on shaping the Earth's surface requires the examination and documentation of analogous tectonic and climate changes of the past, working with the paradigm that past environmental changes are keys to understanding the future.

A France–New Zealand research program, which also involves institutions from several other countries, aims to disentangle the impact of tectonics and climate on the landscape evolution of New Zealand over the past million years, at a very high resolution timescale—with steps as small as 100 years, i.e., relating to events such as earthquakes, tsunamis, and cyclones. The 5-year "Matacore" program (whose name derives from the Matakaoa debris flow coring program, although the program scope is larger than that) began in January 2006 during Leg 152 of R/V *Marion Dufresne*. The research team collected 31 sediment cores, cumulating 600 meters of soft sediment, during a 15-day survey around New Zealand. Preliminary results of the program show complex interactions between tectonics and climate.

The Convergent Margin of New Zealand: A Unique Location

Convergent margins are the locations of major relief formations due to tectonic activity, while the Pleistocene period (1.8–0.01 million years ago) was a time of large-scale climatic shift, from dry and cold glacial conditions to wet and warm interglacial conditions. New Zealand is unique in that it is situated astride an active plate boundary at the critical junction between northern tropical and Southern Ocean climate influences. There, the combined actions of intense tectonic activity and the drastic glacial-interglacial climatic changes are overamplified and can be differentiated. To the north, the Pacific plate subducts beneath the Australia plate, while to the south the Australia plate plunges beneath the Pacific plate. Between the two subduction zones, approximately 560 kilometers of dextral shear has occurred along the Alpine Fault (Figure 1).

New Zealand occupies a unique position of influence in the global ocean and climate circulation systems. Its landmass lies across the westerly wind belt, where due to extreme weather conditions, the 40° and 50° latitudes have earned the nicknames the "Roaring Forties" and the "Screaming Fifties." It guides the subpolar and subtropical ocean currents affecting the latitudinal position of circumglobal subtropical and sub-Antarctic fronts. The fronts separate nutrient-poor subtropical and nutrient-rich sub-Antarctic water masses, which transport a substantial portion of the globe's heat and energy into the Pacific Basin around New Zealand, as part of the abyssal "ocean conveyor" system.

This combined tectonic and climatic setting results in large amounts of sediment eroded from New Zealand's mountainous landscape and rapidly deposited onto adjacent sedimentary basins. These sediments represent high temporal resolution archives of complex climate-tectonics interactions reaching back many thousands of years beyond historical records.

Coring the Marine Sediment Record Around New Zealand

Thirty-nine scientists and students from 20 research institutes in four countries (France, New Zealand, the United States, and Germany) worked together to retrieve and process 31 sediment cores recovered from the Tasman Sea and the southwestern Pacific Ocean in the New Zealand region (Figure 1). They used the unique, nondestructive long corer available on board the French R/V *Marion Dufresne*. The cores were sampled from the canyons off the west coast of New Zealand's South Island that bathe into the different layers of the stratified water masses of the Tasman Sea and into the Hikurangi subduction margin on the east coast of New Zealand's North Island.

Preliminary results from the program confirm the complex interactions between tectonics and climate. For example, the west coast sediments are softer than those of the east coast; this is most likely because of the presence of numerous ash layers along the east coast due to the proximity of the Taupo Volcanic Zone and a long-term dominant winds regime flowing eastward. On the west coast, the canyons that transport catastrophic sedimentation—associated with large earthquakes generated along the Alpine Fault and accommodating the Southern Alps uplift—exhibit a strong overprint of Milankovitch cyclicities in levees [*Nelson and Wilson*, 2007]. On the east coast, cross-shelf to deep marine cores show that climate change controlled flood sediment delivery at the coast.

On a regional scale, climatically driven sea level changes exposed the shelf on a 40- to 100-kiloyear-cycle basis and resulted in the overall instability of the margin—by lowering hydrostatic pressure and increasing sedimentation rates at the shelf edge—with oversteepening megasediment wave deposits [*Paquet*, 2007]. These sediments are subsequently remobilized into large mass transport deposits, as best exemplified by the approximately 600-kiloyear-old Matakaoa Debris Avalanche [*Joanne*, 2008].

These sedimentary archives will help elucidate the dumping of terrestrial sediment into the marine realm and catastrophic submarine processes. These archives hold the key to differentiating tectonic and climatic signals in geological records and unraveling their complex interactions with human activities in shaping the Earth's surface.

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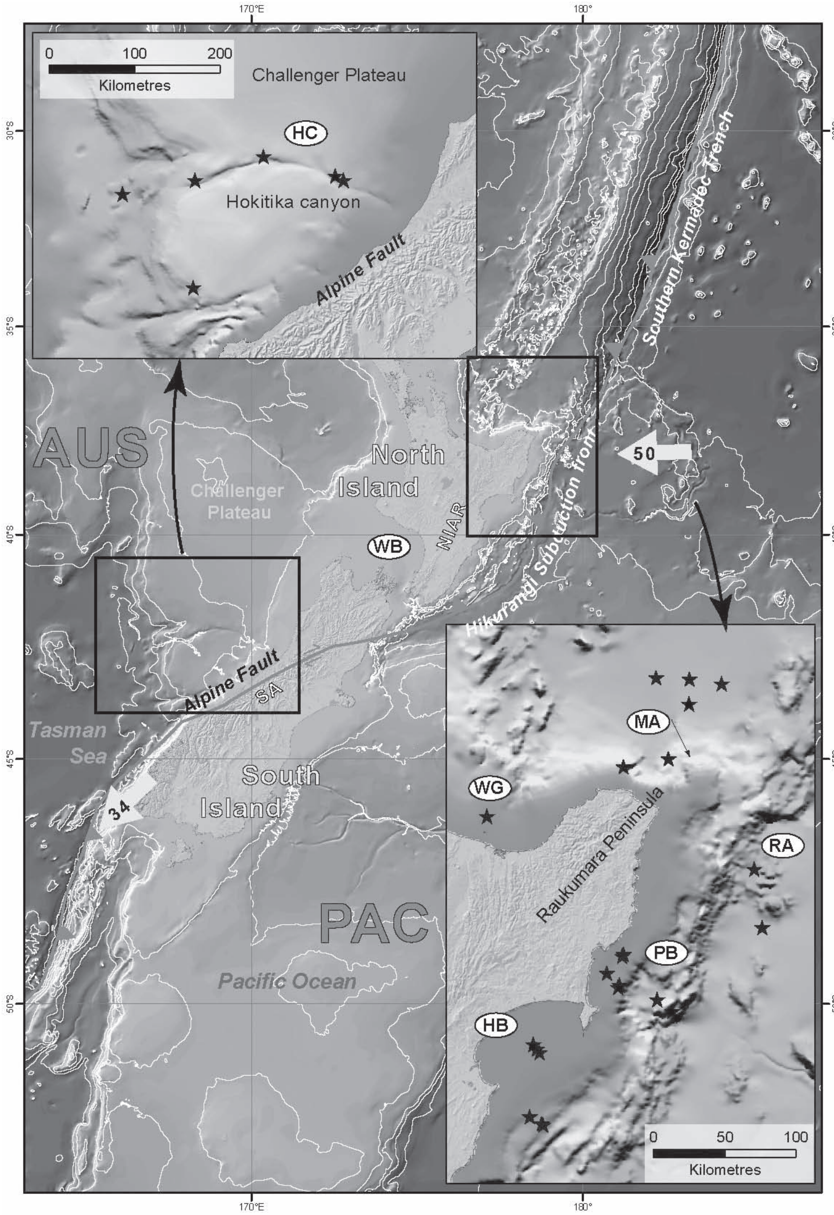

Fig. 1. Tectonics of the New Zealand region. The red curve is the Pacific-Australia (PAC-AUS) plate boundary. The yellow arrows indicate PAC relative motion with regard to AUS, with the rates in millimeters per year. Ovals show the R/V Marion Dufresne *Leg 152 (MD152) site survey area where long cores (indicated by stars) were collected. The Hokitika Canyon (HC) drains the shelf, transporting sediments eroded from the Southern Alps (SA), including catastrophic sediments such as earthquake-triggered turbidites. Wanganui Basin (WB) contains less than 2000 meters of sediments deposited in less than 2 million years. Hawkes Bay (HB) is a fore-arc basin containing sediments eroded from New Zealand's North Island Axial Range (NIAR); the bay's depositional sequences are carefully mapped from three-dimensional analysis of a dense grid of seismic profiles. Poverty Bay (PB) is the site of the Waipaoa Focus Area of the U.S. National Science Foundation-MARGINS Source to Sink program, which serves as a reference for high terrigenous sediment flux and shelf entrapment for anthropogenic effects on a virgin system, and for sediment-tectonic interactions on a steep and unstable continental slope. RA is the Ruatoria mega-avalanche that has been reworked into the subduction. MA is the Matakaoa Avalanche on the Raukumara fore-arc basin, which has experienced repetitive large failures during the past million years. WG is Whakatane Graben, where one core was collected to help constrain the rate of normal faulting. Original color image appears at the back of this volume.*

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Japanese L-Band Radar Improves Surface Deformation Monitoring

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The termination of the Japanese Earth Resources Satellite (JERS 1) in October 1998 and the subsequent delay of the launch of its successor, the Advanced Land Observing Satellite (ALOS), caused a troublesome interruption in the availability of L-band synthetic aperture radar (SAR) data to the several research institutions and government agencies in Japan that had been studying surface deformation by SAR techniques since the Japan Aerospace Exploration Agency (JAXA, formerly the National Space Development Agency of Japan) launched JERS 1 in 1992.

SAR is an all-weather type of sensor that is suitable for the derivation of disaster mitigation information, and—as shown, for example, by *Massonnet and Feigl* [1998]—interferometric SAR (InSAR) techniques can be used to derive precise ground surface deformation maps associated with earthquakes, volcanism, landslides, and slow tectonic motions, as well as with oil pumping and water withdrawal, with fine spatial accuracy. The electromagnetic similarity (coherence) between two SAR images acquired over the same area before and after an event—for instance, an earthquake—is measured, and where appropriately high coherence is achieved, the change in the distance between SAR and the ground target can be derived with fine (centimeter) precision. Both airborne and spaceborne SAR systems are commonly used, although the latter often are preferred due to their long-term monitoring capacity and global coverage.

The JERS 1 SAR operated with L-band frequency (23.6-centimeter wavelength), which proved advantageous compared with other contemporary SAR satellites operating with shorter wavelengths (C-band, 5.6-centimeter wavelength), in that the longer L-band wavelength provides better capacity to maintain coherence in forested and densely vegetated areas. When several major disasters subsequently occurred in Japan—including the volcanic eruptions of Mount Usu (March 2000) and the volcano on Miyake Island (July 2000), and the major earthquake in Niigata-Chuetsu (October 2004)—C-band SAR data from the European Space Agency's (ESA) Envisat advanced synthetic aperture radar and the Canadian Space Agency's RADARSAT-1 were acquired in efforts to monitor the events. However, because the disaster areas were largely vegetated, good coherence could not be obtained with the short C-band wavelength, highlighting the need for an operational L-band SAR.

Features of the ALOS Synthetic Aperture Radar

On 24 January 2006, after a 6-year delay, JAXA finally launched its long-awaited ALOS. The satellite carries two high-resolution optical sensors—the advanced visible and near infrared radiometer type 2 (AVNIR-2) and the panchromatic remote sensing instrument for stereo mapping (PRISM)—and a phased array type L-band synthetic aperture radar (PALSAR), filling the L-band SAR gap left by the termination of JERS 1. ALOS was launched into a 691.5-kilometer Sun-synchronous orbit with a 46-day repeat cycle. After the initial calibration phase, the satellite started its operation on 24 October 2006 [*Shimada et al.*, 2006].

The PALSAR instrument features L-band frequency (23.6 centimeter), 28-megahertz bandwidth (higher spatial resolution than JERS 1 SAR), and 80 transmit-receive modules to allow for quick off-nadir angle change and full polarimetry.

PALSAR has five operational modes: (1) fine-beam single (FBS): single polarization, 10-meter resolution, 70-kilometer swath (e.g., for InSAR applications); (2) fine-beam dual (FBD): dual polarization (HH+HV: horizontal polarization transmission, vertical and horizontal reception), 20-meter resolution, 70-kilometer swath (e.g., forest monitoring); (3) ScanSAR HH polarization, 100-meter resolution, 350-kilometer swath (e.g., quick

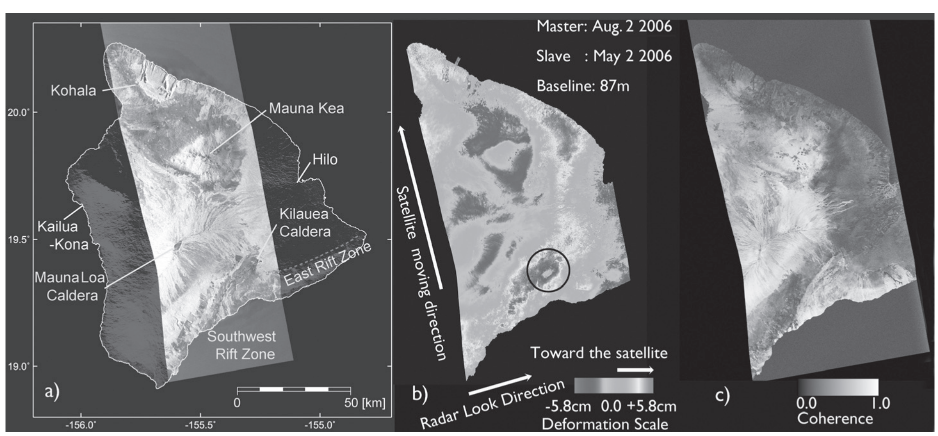
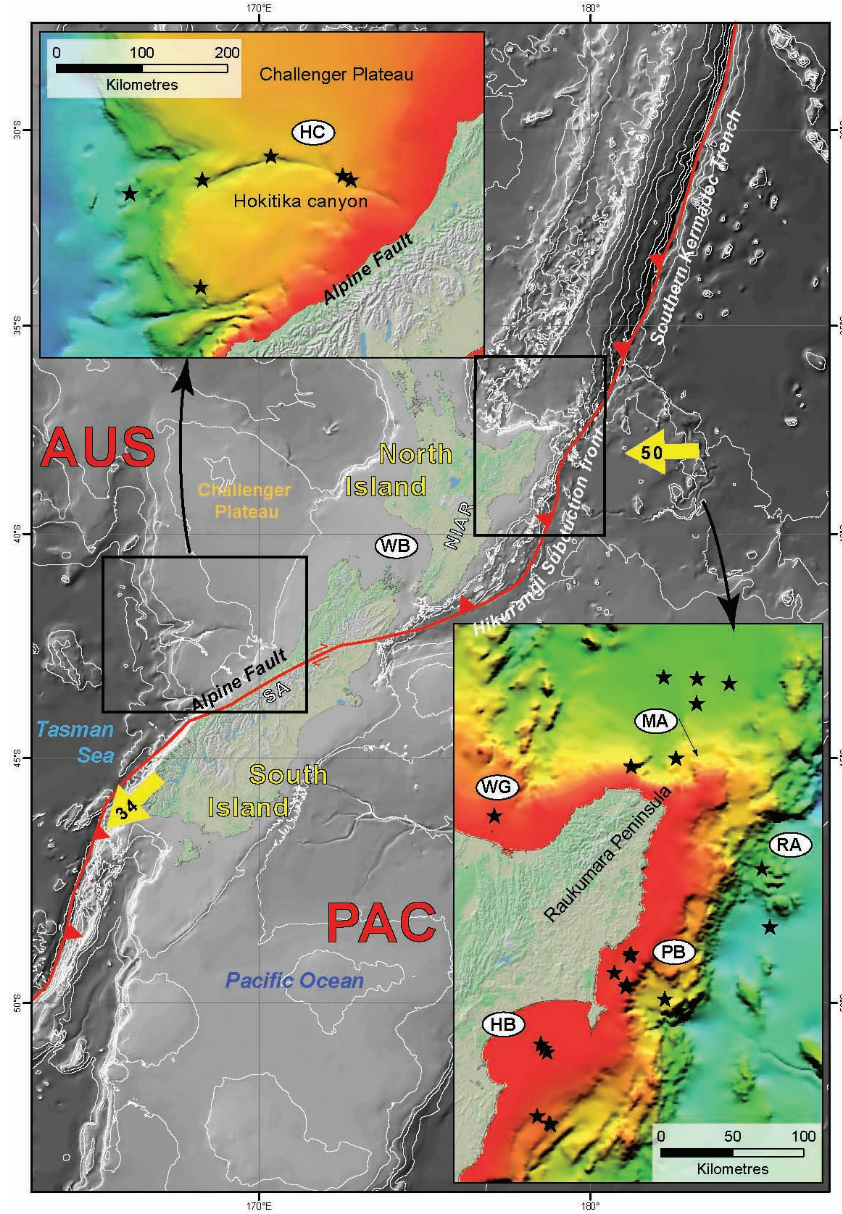


Fig. 1. Phased array type L-band synthetic aperture radar (PALSAR) image over Hawaii on 2 August 2006. (a) Amplitude image showing the reflectivity of the L-band HH polarization. (b) Surface deformation map where the small black circle shows the surface deformation due to magma displacement. (c) Coherence map showing high values, in general, for the entire island. Original color image appears at the back of this volume.



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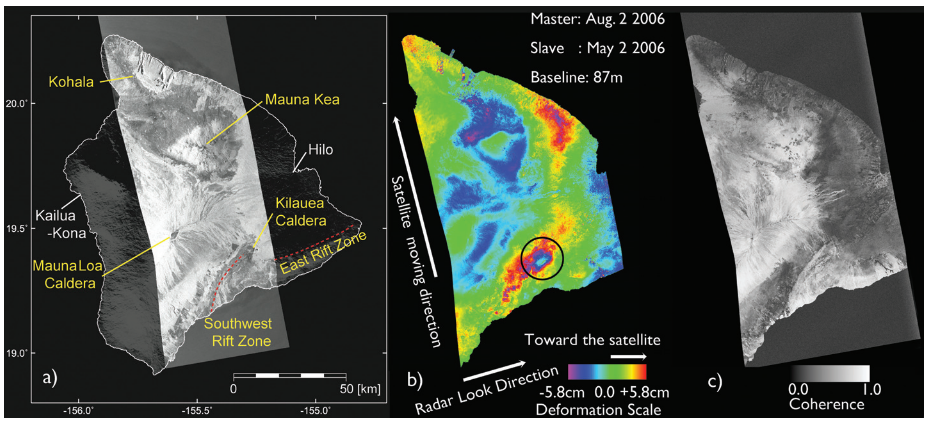

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