Implementation of differential repeat-pass SAR interferometry for
(i) The search for earthquake precursory land-cover deformation
in Taiwan;
(ii) Implementation of HF-OTHR & Infrasonic Imaging for detecting
on-set and real time spreading of tsunamis

Wolfgang-Martin Boerner, Chih-Tien Wang and Kun-Shan Chen

University of Illinois at Chicago, Department of Electrical & Computer Engineering,
Communications, Sensing & Navigation Laboratory
Chicago, IL/USA
Microwave & Remote Sensing Lab
Center for Space & Remote Sensing Research (CSRSR), National Central University (NCU)
CHUNG-LI, TAO-YUAN, TAIWAN
Research Collaborators

Wolfgang-Martin Boerner & Jorge J. Morisaki
ECE/CSN, University of Illinois at Chicago, USA
Alberto Moreira, Kostas P. Papanasssiou, Irena Hajnsek
DLR (German Aerospace Centre), Oberpfaffenhofen, Germany
Eric Pottier, Laurent Ferro-Famil, Andreas Reigber
IETR, UMR CNRS-6164, PMOR, Campus de Beaulieu, Rennes, France
Motoyuki Sato, Takeshi Hamasaki, Koichi Iribe
Tohoku University, CNEAS, Kawauchi, Sendai, Japan
Stuart J. Anderson
DSTO HF-Radar Division, Edinburgh, South Australia
Yoshio Yamaguchi and Hiroyoshi Yamada
Niigata University, Info-Eng, Niigata, Japan
Jong-Sen Lee, Tom L. Ainsworth, Dale L. Schuler, Mitchell Grunes
Naval Research Laboratory (NRL), Washington, DC, USA
Kun-Shan Chen, Chih-Tien Wang, Chung-Pai Chang
CSRSR, National Central University, Taiwan
Jeffrey K. Weissel, Kristina Rodriguez-Czechlewski
Lamont-Doherty Earth Observatory, Columbia University, New York, USA
Wool Moon & Sang-Eun Park
ESI3, Seoul National University, Kwanuk-ku, Seoul, Korea
Joong-Sun Won & Lee Seung-Kuk
ESS, Yonsei University, Seodaemun-ku, Korea
Terrestrial Ionosphere & Magnetosphere
ELF/ULF Electromagnetic Spectrum
Communications, Sensing & Navigation Lab

Tectonic Stress Electromagnetic Signatures
Recent electromagnetic signatures associated with the Chi-Chi and Chia-Yi earthquakes of 1999.
Recent electromagnetic signatures associated with the Chi-Chi and Chia-Yi earthquakes of 1999.
ULF Tectonic & Spherics Signatures at About .1 to 20 Hz
Northridge Tectonic Stress Signatures during 1993 December to 1994 February
Averaged Tectonic Stress Signatures during Northridge Earthquake
Earthquake

- Blue circle: Radius 50 Km
- Red line: Chelungpu fault
- Star mark: Three sample earthquakes
- Black circle: Earthquakes $M \geq 5.0$

Earthquakes occurred in six blue circles (except HC, LP) were compared with the anomaly
Recent electromagnetic signatures associated with the Chi-Chi and Chia-Yi earthquakes of 1999.

The raw data in HL and LP in March, April May, August, September, October, November and December, 1999.
Recent electromagnetic signatures associated with the Chi-Chi and Chia-Yi earthquakes of 1999.

The raw data in LY station in March, April May, August, September, October, November and December, 1999.
The Western Pacific Rim of the Circum Pacific Rim and Taiwan
The Western Pacific Rim of the Circum Pacific Rim and Taiwan

From gis.geo.ncu.edu.tw/ 921
The Western Pacific Rim of the Circum Pacific Rim and Taiwan

地震的地震與地體構造
(1900-1999)

- 6>M≥7
- 7>M≥8
- 8>M≥9
- 9>M≥10
- 1>M≥2
- 2>M≥3

地震資料來源
1. 交通部中央氣象局
2. 中央研究院地球科學研究所
Brief introduction of DIFF-RP-IN-SAR

6D DIFFERENTIAL SAR INTERFEROMETRY
HOW DOES IT WORK?

- Three-pass “repeat track” interferometry uses two baselines \((B_1, \alpha_1)\); \((B_2, \alpha_2)\) to acquire interferograms at different times.
- Despite exaggeration in picture on the right, the incidence angles and absolute ranges are nearly the same.
- Now suppose that the surface deformed slightly between the second and third acquisitions in such a way that the range changed by an amount \(\Delta \rho\).
- In the repeat-track implementation of interferometry, the signal travels each path twice, since the transmitter and receiver are in the same place. Therefore, the interferometric phase is

\[
\Delta \phi = \frac{2\pi}{\lambda} 2 \times \text{range} = \frac{4\pi}{\lambda} \text{range}
\]
Differential SAR Interferogram for Northridge Earthquake: First Test-Image

Northridge Earthquake:
1994 January 17
Differential SAR Interferogram for Northridge Earthquake: Second Test-Image

Northridge Earthquake:
1994 January 17
Differential SAR Interferogram for Northridge Earthquake: Third Test-Image

Northridge, California 1994 M=6.8 Earthquake
JERS-1 Repeat Pass Interferometry

100 cm / cycle displacement

Northridge Earthquake:
1994 January 17
Great Hannshinn-Awaji Earthquake, JERS-1 SAR Differential Interferometry

Dates of acquisition: Feb. 6 1995, Sept. 9 1995

Perpendicular baseline: 125m
Brief introduction of **DIFF-RP-IN-SAR**

**DIFFERENTIAL SAR INTERFEROMETRY**

Example: 1995 North Sakhalin Earthquake (M 7.6)

Monitoring of ongoing surface deformation along Cheleng-Pu fault

Data fusion of DEM and RADARSAT SAR images
By CSRSR.

Interest area

3800m

0m
Monitoring of ongoing surface deformation along Cheleng-Pu fault
The destruction along the Cheleng-Pu fault caused by the Chi-Chi earthquake of 1999 September 21
Monitoring of ongoing surface deformation along Cheleng-Pu fault
The destruction along the Cheleng-Pu fault caused by the Chi-Chi earthquake of 1999 September 21
The destruction along the Cheleng-Pu fault caused by the Chi-Chi earthquake of 1999 September 21
Recent electromagnetic signatures associated with the Chi-Chi and Chia-Yi earthquakes of 1999.

The raw data in LY station in March, April May, August, September, October, November and December, 1999.
Chia-yi

Sandwiched between west-propagating mountain belt and stable basement high

with major faults and abundant present and historical seismicity
Earthquake locations from BATS; Fault data from MOEA
2 earthquakes occurred on 10/22/1999 in Chiayi area

Combined surface deformation of the two eqs were observed by SAR Interferometry ($B_n=232m$)

Approx. 2 fringes can be observed from interferogram, representing 5~6cm slant range deformation
MAJOR TECTONIC PLATES OF THE WORLD

Eurasian plate
Juan de Fuca plate
Pacific plate
Caribbean plate
Cocos plate
Nazca plate
South American plate
African plate
Arabian plate
Australian-Indian plate
Antarctica plate

From BBC news site
South-East Asia
2004 BOXING DAY TSUNAMI
A tsunami is a series of traveling ocean waves of extremely long length generated primarily by earthquakes occurring below or near the ocean floor.

Tsunami waves propagate across the deep ocean with a speed exceeding 800 km/h (≈ 500 mph) and a wave height of only a few tens of centimeters or less.

As they reach the shallow waters of the coast, the waves slow down and their height increases up to tens of meters (30 ft) or more.

Source: NOAA
Tsunami Physics

1. Before the earthquake

The plate holding the Indian Ocean was sliding under the continental plate (holding Indonesia and much of Asia) at about 6 cm per year. The continental crust was bent thanks to the constant pressure of collision.

2. During the quake

The fault ruptured violently, allowing the continental crust to unbend and causing portions of the sea floor to move up or down by several metres. The water above the fault responded in kind, creating a wave crest and trough.
One wave crashed towards the nearby shore of Indonesia. Another barrelled westwards at about 800 km per hour in deep water, with a wavelength of 100 km and an average wave height of just tens of centimetres.

When the wave entered shallow waters, it slowed to tens of kilometres per hour, its wavelength shortened to about 5 km, and its height is thought to have soared to more than ten metres. The trough of the wave often hits before the crest (as shown).
Kalutara Beach, Sri Lanka

Receding Waters from Tsunami, Imagery collected December 26, 2004
DigitalGlobe
Tsunami Wave Appearance

Source: www.waveofdestruction.org

• A tsunami wave crest has three general appearances from shore:
  – Fast-rising tide
  – Cresting wave
  – A step-like change in the water level that advances rapidly (called a bore)

• Series of waves
  – Most tsunamis come in a series of waves that may last for several hours
  – The outflow of water back to the sea between waves can cause more damage than the original incoming wave fronts
  – The first wave is rarely the largest
Banda Aceh Overview

(Before Tsunami)
Imagery collected April 12, 2004
DigitalGlobe

(After Tsunami)
Imagery collected January 2, 2005
DigitalGlobe
The 26-Dec-2004 Tsunami
Indian Ocean Tsunamis: 1833 & 2004

Hannah Fairfield/The New York Times, Science Section, January 4, 2005
“Natural hazards are inevitable. Natural disasters are not.”
Jindalee transmitting facility, Harts Range
Jindalee receiving site, Mt Everard
Jindalee map of significant waveheight off the NW coast of Australia; wind direction vectors superimposed.
HFSWR signature of a low frequency ocean wave transient with (perhaps) some similarity to a tsunami

(a) Normal sea conditions showing energy concentrated in short gravity waves

(b) Low frequency wave packet arrives with little dispersion at longer scales (wavelengths) then progressive dispersive delay at intermediate scales
Ionospheric response to an atmospheric gravity wave and its HF radar signature

Equivalent vertical speed of isoionic surface for a propagating AGW
(recorded May 1985)

Azimuth-range-Doppler map of HF skywave radar sea echoes perturbed by AGW

Track of DEMETER above Sumatra on March 23, 2005
Infrasonic Recording Sensor System with Typical Pressure Amplitude of Infrasonic Signals

According to A. J. Bedard:
NAAA-ETL, Boulder, CO
Infrasound from the 2004-2005 earthquakes and tsunami near Sumatra

Milton Garces, Pierre Caron, and Claus Hetzer
Paths of infrasound signals from earthquakes
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<td>-4</td>
<td>-7</td>
<td>-11</td>
<td>-14</td>
<td>-17</td>
</tr>
</tbody>
</table>

GLF, SLF, ULF, ELF, LF-HF, UHF-EHF, IR, UV, X-$\gamma$, Cosmic

$\leftarrow$ infra-sonic $\rightarrow$ sonic $\leftarrow$ supra-sonic $\rightarrow$ optical

Electromagnetic Spectrum
FOUNDATIONS AND RELEVANCE OF MODERN EARTH REMOTE SENSING & ITS ACTIVITIES

Conclusions:

The Electromagnetic Spectrum:
A Natural Global Treasure

Terrestrial Remote Sensing:
The Diagnostics of the Health of the Earth