Surface Anomalies Prior to Earthquakes

Habibeh Valizadeh, Shattri B. Mansor
Husaini Omar and Farid Azad
Department of Civil Engineering
Universiti Putra Malaysia
Serdang, Selangor
Malaysia
shattri@eng.upm.edu.my

Introduction

Recently, new theories on underground geophysical and geochemical interactions occur during preparation stages of earthquakes and the resultant measurable variations have been put into test and some warning factors were suggested as earthquake precursors.

In case of oceanic and coastal earthquakes, with thinner crust, these pre-earthquake activities may be detected through secondary oceanic and atmospheric phenomenon.

Earthquake Precursor ≠ Earthquake Prediction

Earthquakes?

Are they really predictable?

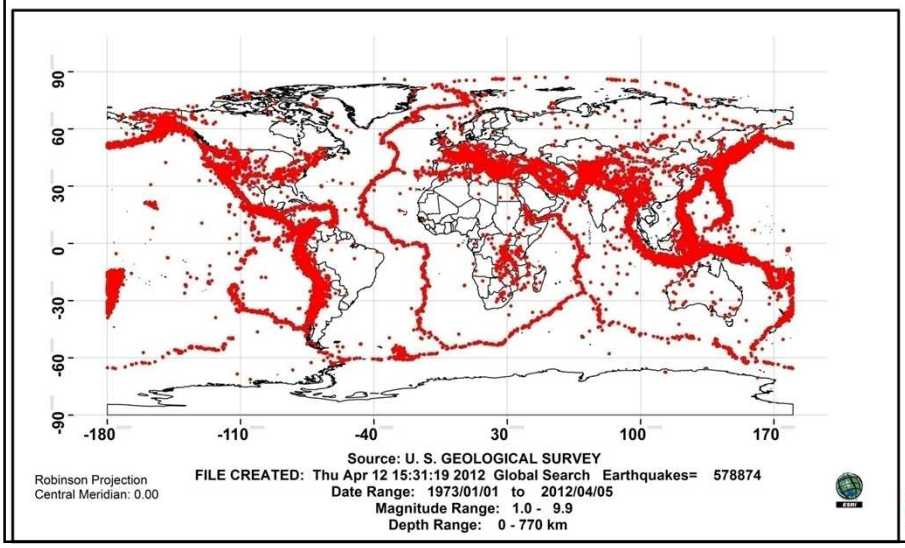
- •Vibrations in the earth are caused by sudden release of energy.
- •This energy is produced somewhere within the crust.
- •Its formation and existence produce phenomena under, on and above the ground.

- •Satellite-based measurements and ground observation networks can be specialized to monitor the earthquakes-related changes.

Earthquake Precursors

- Temperature anomalies
- SLHF (higher atmosphere-surface energy exchange)
- Chl-a concentration
- Radon gas emission
- Crust Deformations
- Strange cloud formation
- Seismic pattern

Frequency and distribution(1973-2012)



Earthquake Precursors

Short Term
Hours/Days/Weeks

Long Term
Months/Years/Decade

- **Seismology**
- **Remote Sensing**
- **In-situ measurement**

→ **Earthquake event**

Our concern is:

Remote Sensing → **Earthquake precursors prior to the event**
(Hours/Days/Weeks)

Monitoring the Precursors

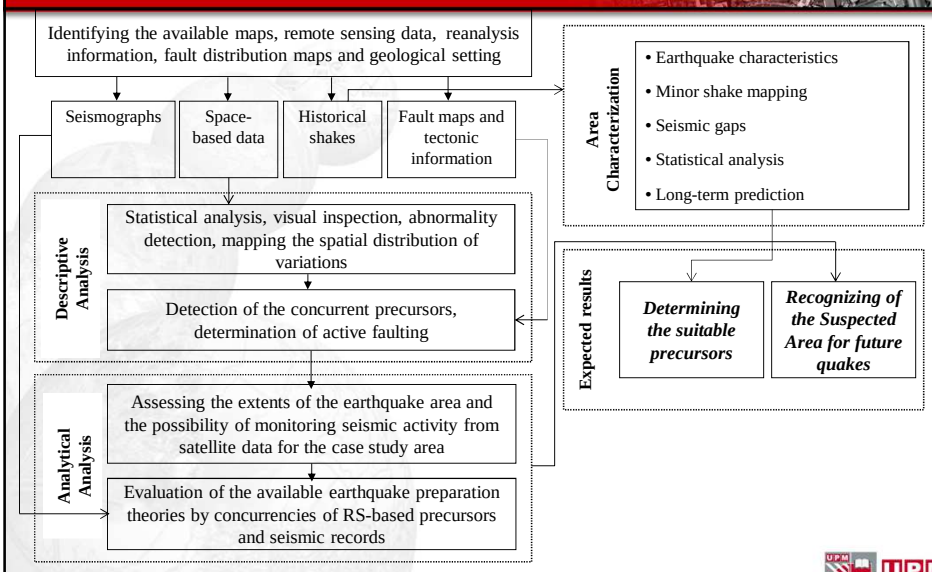
Possibilities

- Free available remote sensing data covering large scales allow monitoring the earth's surface.
- Data providers produce high-quality and trustable data using in-situ measurement networks and validation models.

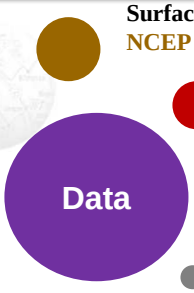
Problems

- Attenuation of received signals.
- Significant seasonal and natural changes on the surface masking the earthquake-related anomalies.
- Anomalies due to human activities.
- Limited knowledge on the local fault regime; earthquake formation site and places of vibration.
- Low resolution remote sensing data and insufficient number of ground stations.

Workflow



Data



Surface Latent Heat Flux from NCEP

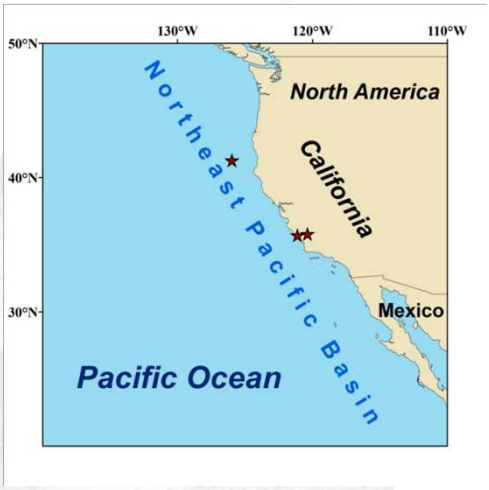
Surface Temperature from ASTER, AVHRR or AMSR-E

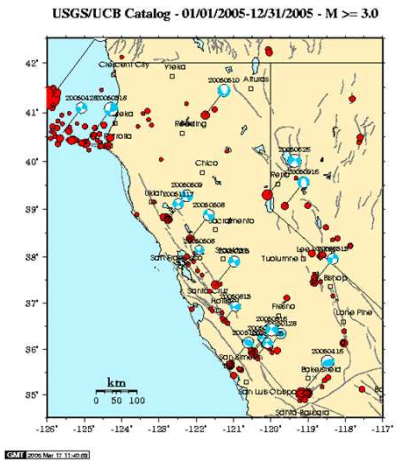
Chlorophyll-a from MODIS

Upwelling Indices from PFEL

NCEP: National Center for Environmental Prediction
ASTER: Advanced Spaceborn Thermal Emission and Reflection Radiometer
AVHRR: Advanced Very High Resolusion Radiometer
AMSR: Advanced Microwave Scaning Radiometer
MODIS: Moderate Resolution Imaging Spectrodiometer
PFEL: Pacific Fisheries Environmental Laboratory

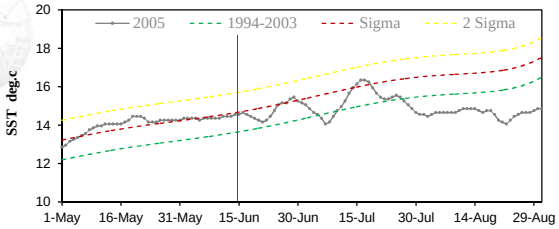
Oceanic Case Studies

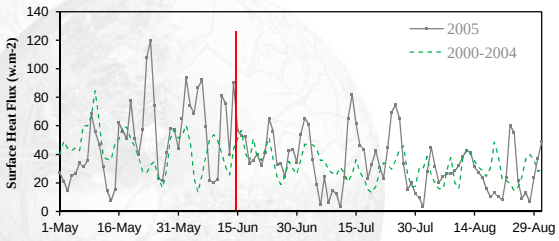




Earthquake of California 2005

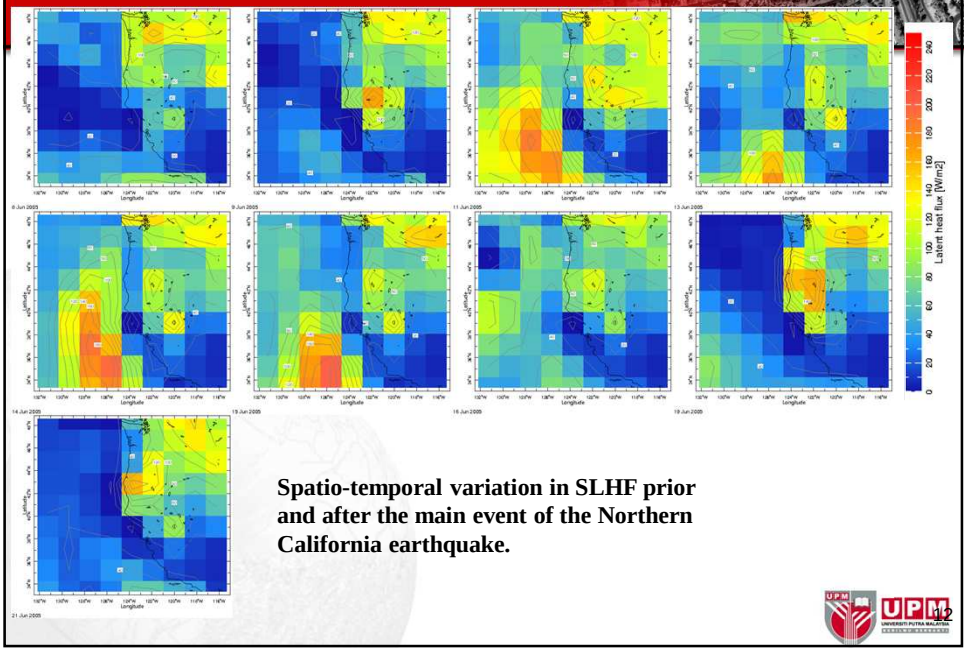
Time series of thermal anomalies at the epicenter of the California earthquake showing high values a month before the main event. dashed line is the 10-year average of *SST* for the region.





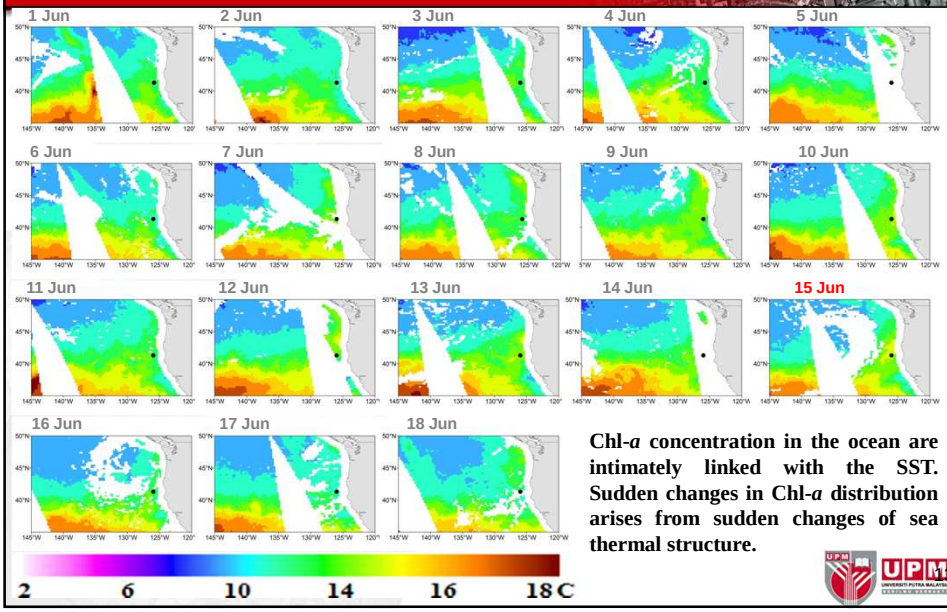
Temporal variation in *SLHF* of the California earthquake covering the epicenter pixel showing increase in some occasions prior to the main event; dashed line is the 5-last-year average of *SLHF* for the region.

Changes in SLHF



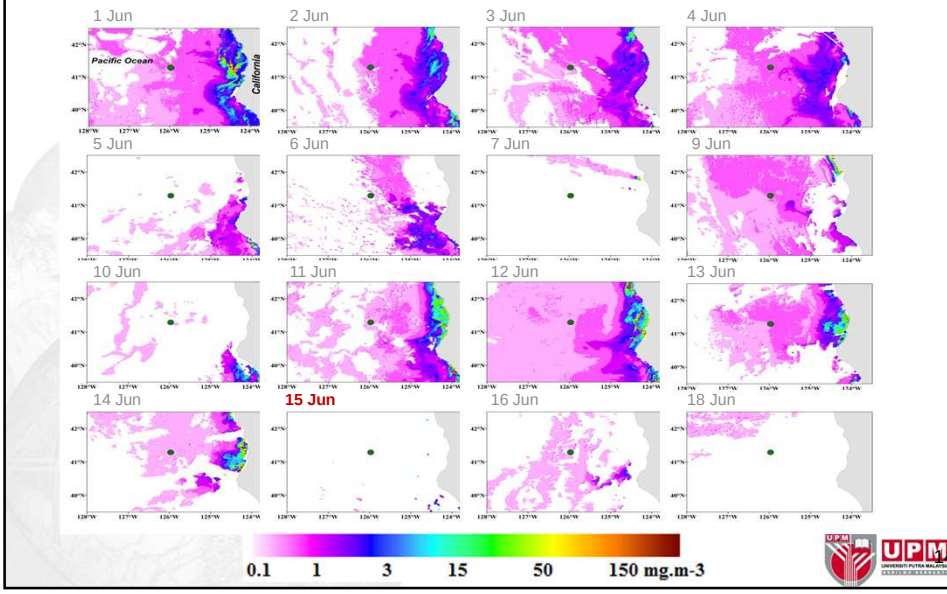
Spatio-temporal variation in SLHF prior and after the main event of the Northern California earthquake.

SST Anomalies



Chl-*a* concentration in the ocean are intimately linked with the SST. Sudden changes in Chl-*a* distribution arises from sudden changes of sea thermal structure.

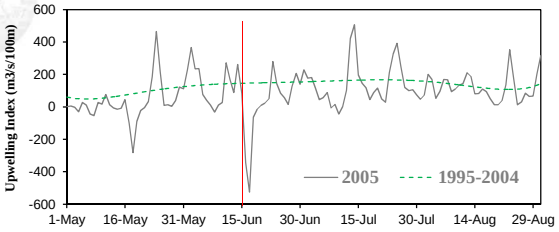
Variation of Chl-a

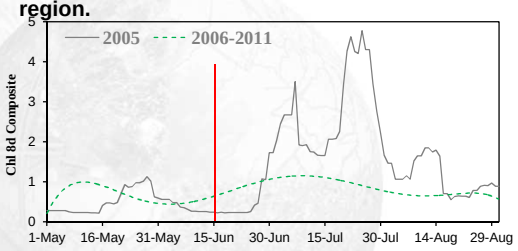


Upwelling Index

- Two major factors which cause rising in Chl-*a* concentration are ocean upwelling and sea surface temperature both of which are pre seismic indicators.

Daily averaged upwelling index for Northern California earthquake showing maximum rise some days prior to the main event; dashed line is the 10-year average of upwelling index for the region.





8-day averaged Chl-a for Northern California earthquake showing some high Chl-*a* matched the upwelling in terms of location and time; dashed line is the 6-year average of Chl-a for the region.

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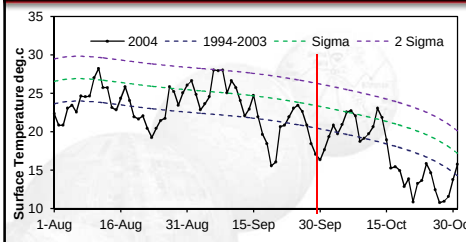
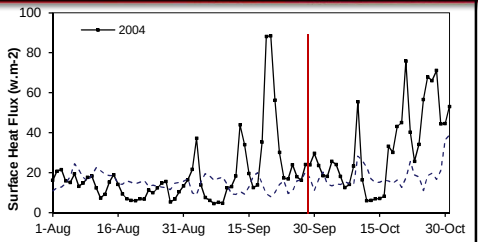
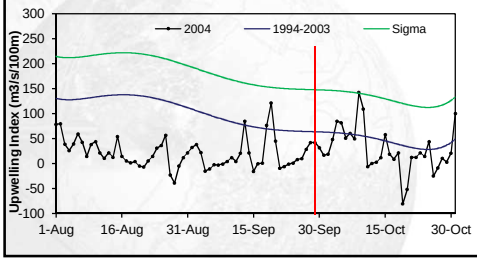
Earthquake of California 2004



The anomalous SLHF values before and during the earthquake of September 28, 2004; Red bar indicates the day of the main event.



Time series of surface temperature; shows several anomalies during the preparation stage and sudden fall after the main event.



Daily averaged upwelling index, showing rises before the main event.

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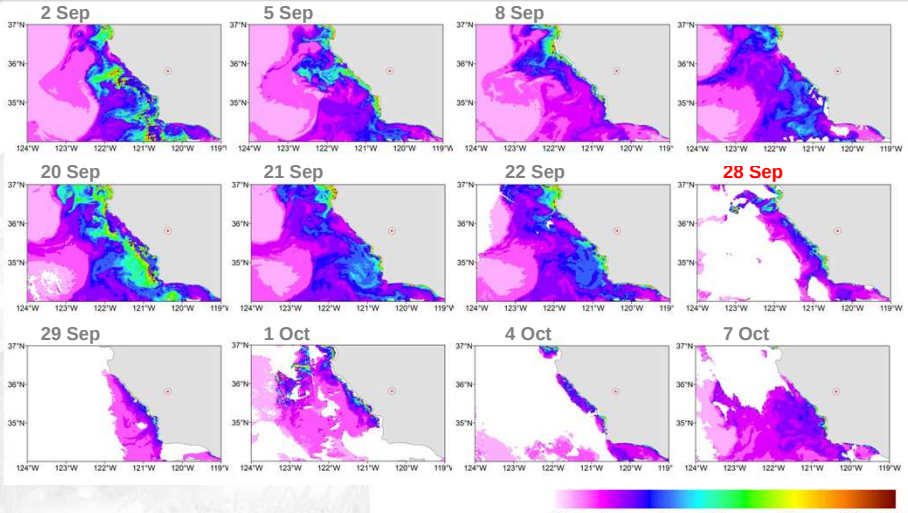
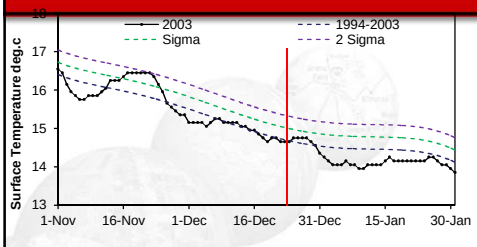
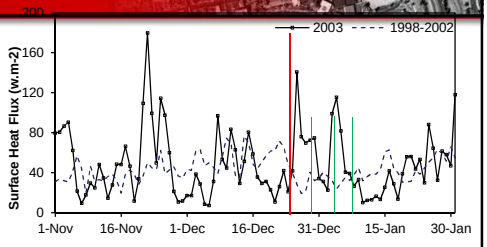
Variation of Chl-a



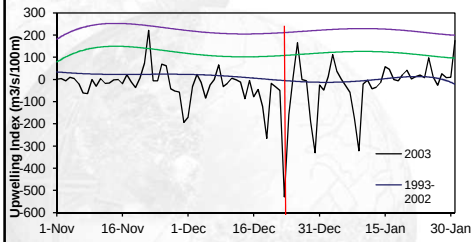
Temporal distribution of Chl-a concentration ; the increasing trend to the day of the event and general decrease in the area afterwards is obvious.

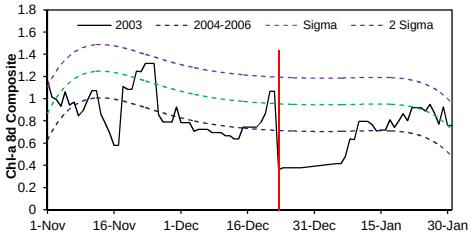
Earthquake of California 2003





The SST and SLHF time series of the epicentral oceanic water of the earthquake of December 22, 2003 generally higher before the earthquake. The effect of aftershocks during the second half of December is also shown.





Daily averaged upwelling index and 8-day composite Chlorophyll-a time series, showing anomalies in some occasions from one month before the main event followed by a sudden downwelling and decrease immediately after that.

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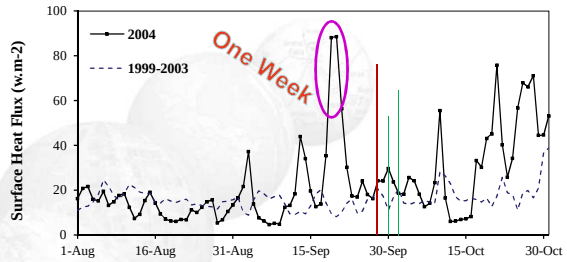
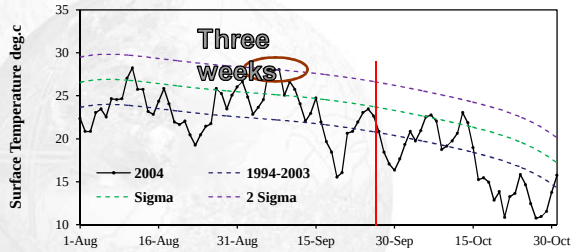
Thermal and Heat



$$F_{LH} = LvCeUa\,(qs - qa)$$

FLH: Surface evaporation
Lv: Latent heat of condensation
Ce: Surface exchange coefficient for moisture
Ua: Surface wind speed,
Qs: Saturated specific humidity at ocean surface
Qa: Air specific humidity at 2 m above the surface.

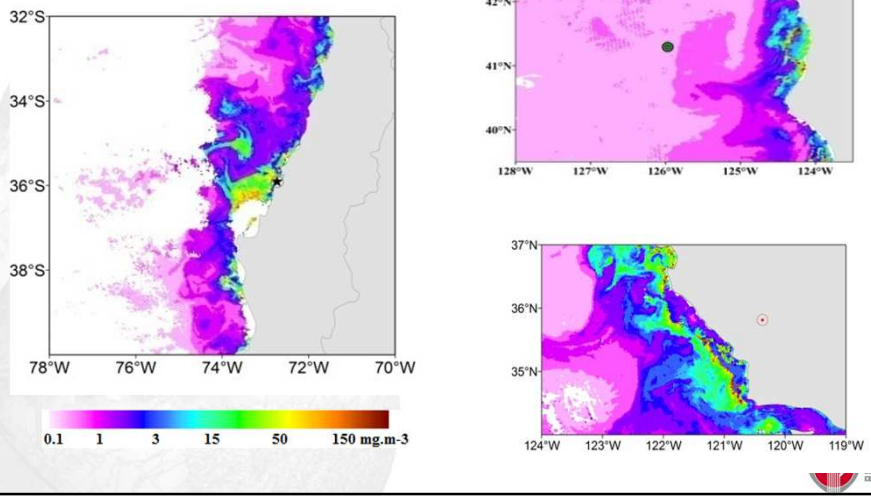


$$T_s = \gamma\left[\frac{1}{\varepsilon}(\psi_1 L_{sen} + \psi_2) + \psi_3\right] + \delta$$

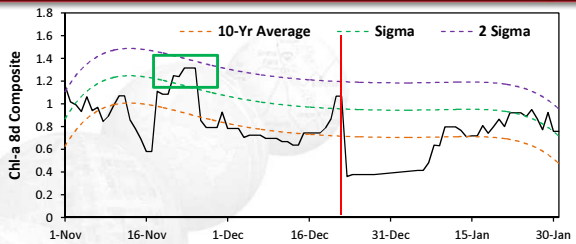
Ts: LST
ε: Surface emissivity
γ and δ: two parameters dependent on the Planck's function
ψ1, ψ2, and ψ3 : Referred to as atmospheric functions (AFs)

Increased Chl-a on ocean surface

High Chlorophyll-a Pattern before the earthquake

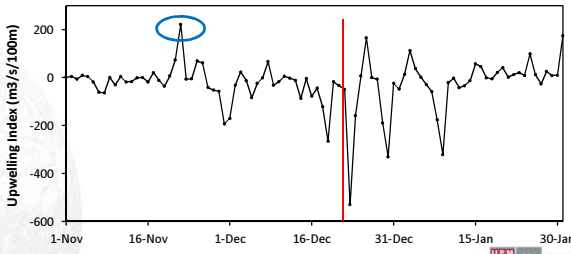


Chl-a & Upwelling

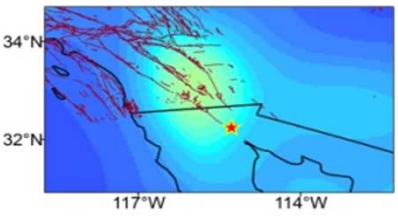


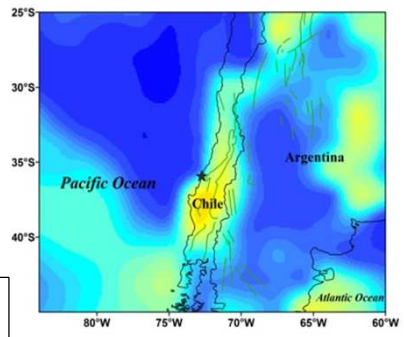
$$[chl\ a] = P_0 * [\ a_\phi(675)\ ]^{P_1}$$

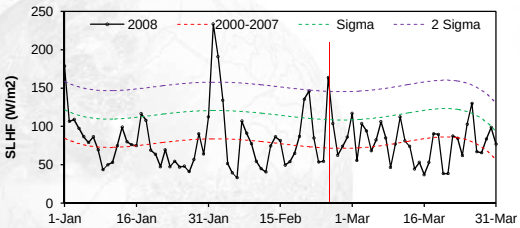
$$\log[chl\ a\ ]_{emp} = c_0 + c_1 \log(r_{35}) + c_2 [\log(r_{35})]^2 + c_3 [\log(r_{35})]^3$$



Increased SLHF & active faults

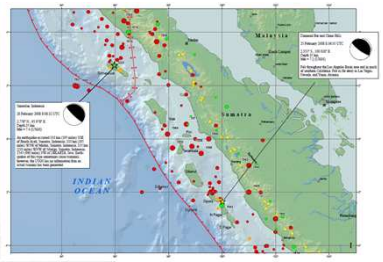




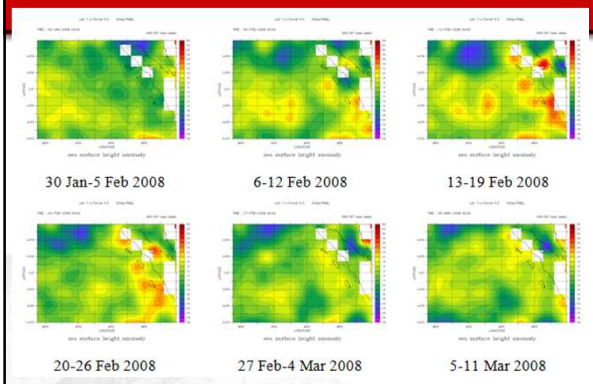


Earthquakes of Indonesia

No.	Place	Date	Longitude	Latitude	Magnitude	Focal Depth (km)
1	Simeulue, Indonesia	Feb 20, 2008	95.978 E	2.778 N	7.4	35
2	Kepulauan, Indonesia	Feb 25, 2008	100.018 E	2.351 S	7.2	35

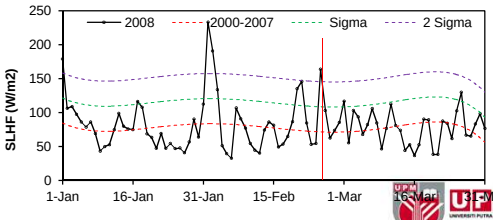


SSH and SLHF Anomalies



Images of SSH retrieved from AMSR-E in the Indian Ocean during the Simeulue and Kepulauan earthquakes of February, 2008 showing significant rises near epicenters one week before and during the earthquake events.

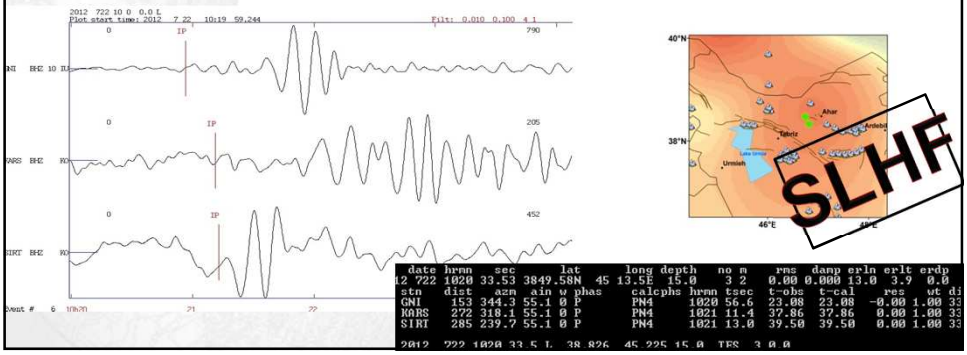
Sharp rises in SLHF values of the pixels covering the epicenter of 25th Feb, 2008 earthquake is observable from the end of January to few days before the main event. Red bar is the day of the main event.



Seismic study

micro-shake detection using seismograph interpretation:

- Evaluating the shaking rate before the main events
- Understanding the possible hidden fault pattern and local faulting activity by statistical analyses of the various information, related to foreshocks and aftershocks.
- Discovering the time and intensity frames of the possible correlation between seismic and remote sensing precursors.



Findings

✓The systematic patterns of SLHF along earthquake origins.

✓Relative humidity, surface and air temperature values are warning signals of an impending earthquake (2-3 weeks prior to the main event).

✓2-3 weeks before the earthquakes the productivity rate of the open ocean water exceeded the average values.

Benefits

Remote sensing techniques allow monitoring the earthquake precursory factors anomalies over large areas to detect tectonic activity and understand the mechanism of earthquake preparation processes to provide possibilities of a reliable prediction of these potential precursors in different parts of the world.

Q & A??

For further information please contact:

Shattri Mansor
Remote Sensing & GIS Research Centre
Faculty of Engineering
Universiti Putra Malaysia
43400 UPM Serdang
Phone: +6019 - 2244333
E-mail: shattri@eng.upm.edu.my