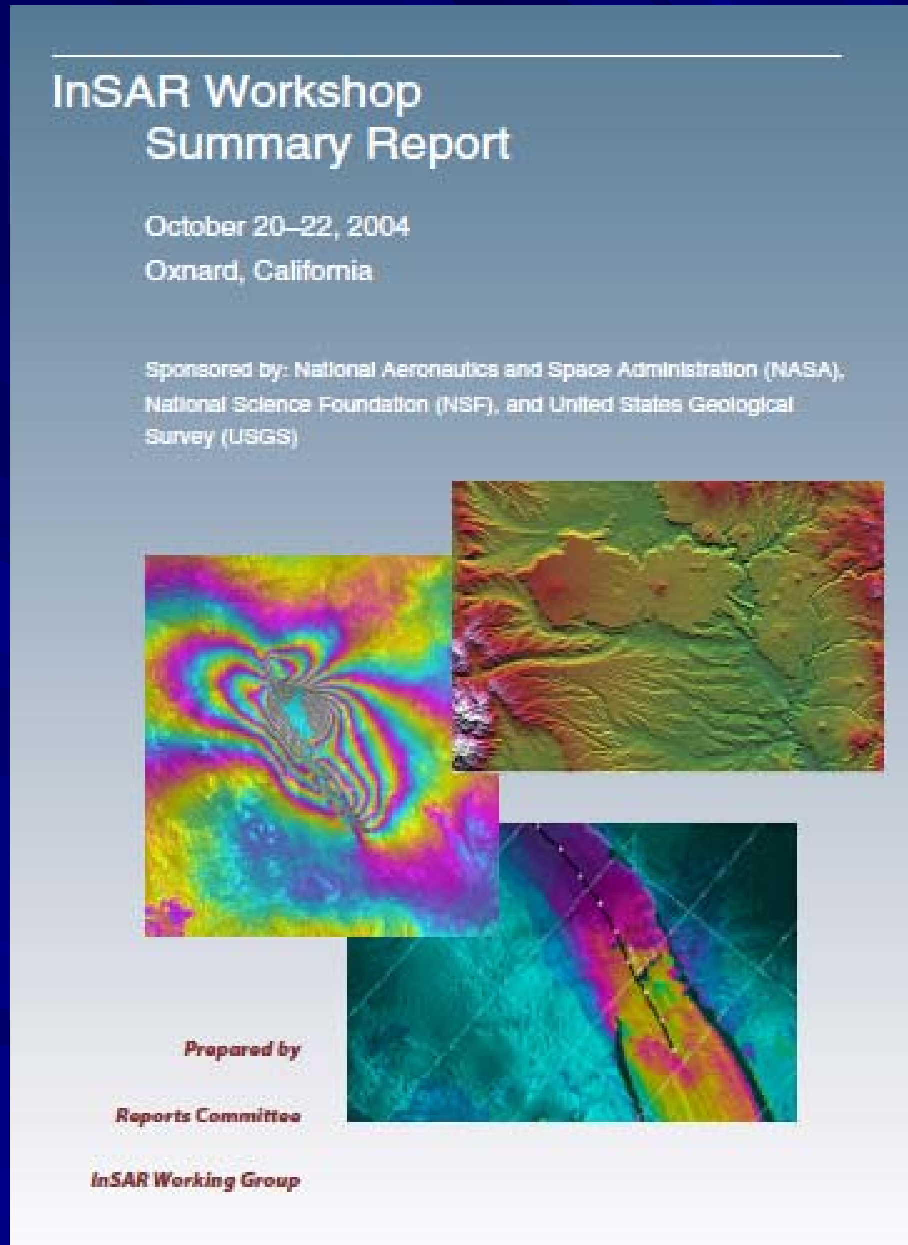
InSARとGPSのCollaboration：
歪蓄積過程モニタリングにむけた期待

Collaboration of InSAR and GPS: Expectation toward the Monitoring of Strain Accumulation Process

橋本　学（京都大学防災研究所）

Manabu Hashimoto (DPRI, Kyoto Univ., Japan)
Email: hasimoto@rcep.dpri.kyoto-u.ac.jp

http://solidearth.jpl.nasa.gov/PDF/InSARWorkshopReport.pdf



InSAR Workshop Summary Report

October 20–22, 2004

Oxnard, California

Sponsored by: National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and United States Geological Survey (USGS)

Prepared by

Reports Committee

InSAR Working Group

Grand Challenge Science Objectives by Discipline: Crustal Deformation

- What mechanisms control the occurrence of transient and steady-state aseismic fault slip?
- What stress transfer processes are important in triggering seismic activity? Are long-range interactions important?
- Are there precursory deformation phenomena for either earthquakes or volcanos and can they be detected with InSAR observations?
- How does magma ascend from a source region to shallow reservoirs? What processes control the further ascent?
- What processes cause/trigger flank instabilities on volcanoes? Are they related to eruption?
- How are earthquake faulting and magmatism interrelated? Can an earthquake along the San Andreas fault trigger volcanism in the Cascades?

InSAR Workshop Summary Report (2004)

What mechanisms control the occurrence of transient and steady-state aseismic fault slip?

- Recent discovery of transient aseismic fault slip in the Cascadia and Japanese subduction zones has been a big surprise to Earth scientists and has raised compelling questions about the causes and effects of such transient events. Close association of these events with micro-seismic tremor activity is even more surprising and bewildering.
- While continuous GPS networks and seismic arrays have played key roles in these discoveries, InSAR imaging has the potential to dramatically improve the spatial distribution of the 3-D deformation field of these events and image the causative deformation sources at depth on the interplate megathrust.
- InSAR has also imaged an aseismic slip event on an intraplate shallow thrust fault that was not otherwise detected.

What stress transfer processes are important in triggering seismic activity? Are long-range interactions important?

It has long been recognized that the static stress changes produced by earthquakes, glacial fluctuations, and magmatic unrest can either advance or retard the occurrence of subsequent seismic and volcanic activity. Current research is very actively elucidating the nature of the earthquake/earthquake interactions, rigorously quantifying the statistical likelihood of linkages, and beginning to shed light on time-dependent processes (e.g., post-seismic relaxation, state/rate fault friction) that influence triggered activity.

However, emerging clues suggest longer-range interactions that are not mechanically understood. Any linkages should have deformation signatures, and synoptic InSAR imaging offers possibly the best means of detecting and elucidating the deformation causes and effects that may link regional earthquake events.

Are there precursory deformation phenomena for either earthquakes or volcanoes and can they be detected with InSAR observations?

This is the Holy Grail for solid-Earth natural hazards research. Current earthquake hazard maps are at a coarse resolution in both time and geography. Such maps depict probability of exceeding a certain amount of shaking (generally that at which damage occurs) over the next 30 to 100 years, depending on the map. The spatial resolution is typically on the order of tens to hundreds of kilometers. These maps are based on information about past earthquakes observed in the geological or historical record. Measurement of crustal deformation, usually acquired using GPS, now provides information on strain rates; generally we find that earthquake rates are higher where strain rates are higher.

The number of GPS stations that can be deployed on the ground limits the resolution of strain, and these stations can be expensive to install and maintain. InSAR can be deployed as a space-based imaging technique that will provide spatially smooth resolution of strain at 100 m, vastly improving resultant hazard estimates by two to three orders of magnitude in terms of spatial resolution.

Are there precursory deformation phenomena for either earthquakes or volcanoes and can they be detected with InSAR observations?

Furthermore, future science studies of crustal deformation will yield insights into earthquake behavior, whether high strain rates indicate the initiation of failure on a fault or quiet release of stress, and how stress is transferred to other faults. These studies will lead to science findings for improvement of earthquake hazard maps both spatially and temporally. Similar studies employing InSAR to map deformation on volcanic terrain can reveal subsurface transport of magma, an important factor affecting eruption probabilities. Detailed maps of the shape of the magma trail give clues as to where pressure may accumulate and also may help constrain the explosiveness of the potential eruption. Global InSAR data will permit this mapping worldwide, covering all potentially active volcanoes.

InSAR has clearly helped the discovery of unexpected processes in the post-seismic period. The continuous surveillance of seismic areas with a dedicated system will undoubtedly reveal the signature of precursory processes should the associated surface displacement be resolvable by InSAR. A lot of unknowns obviously exist in this field, but the quest for signal is worthy of pursuit.

Specific New Data and Technology Needs: Crustal Deformation

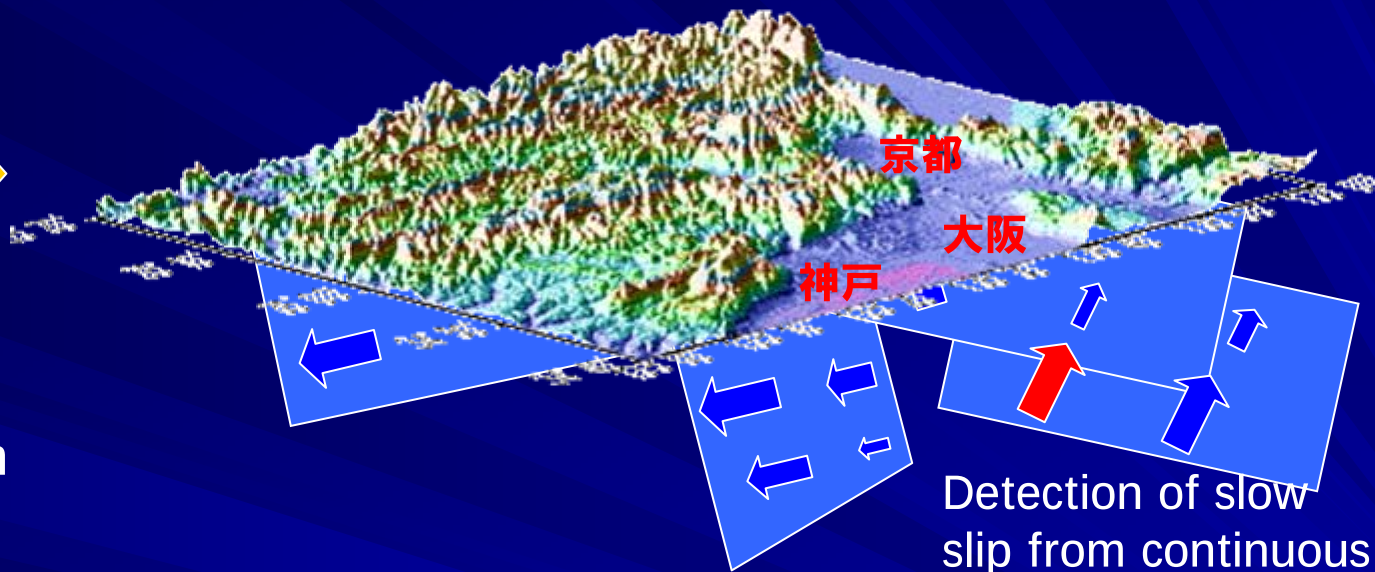
- Basic requirements
  - L-band
  - 8-day repeat cycle
  - Millimeter-scale sensitivity
  - Tightly controlled orbit to maximize usable InSAR pairs
  - Both left and right looking for rapid access and more comprehensive coverage
- Additional requirements
  - ScanSAR operation for wide swaths
  - Increased power and storage to operate 20% of the orbit on average

Strain Accumulation Process

- Basic knowledge for the study of earthquake generation process
- Mainly studied by GPS/conventional surveys
- Main theoretical basis
  - Dislocation theory in half space
  - Friction
- Characteristics
  - Not large signal
  - Spatially heterogeneous
  - Temporally heterogeneous

Quasi-Static Model for Active Faults

Estimate static fault parameters from observed displacments

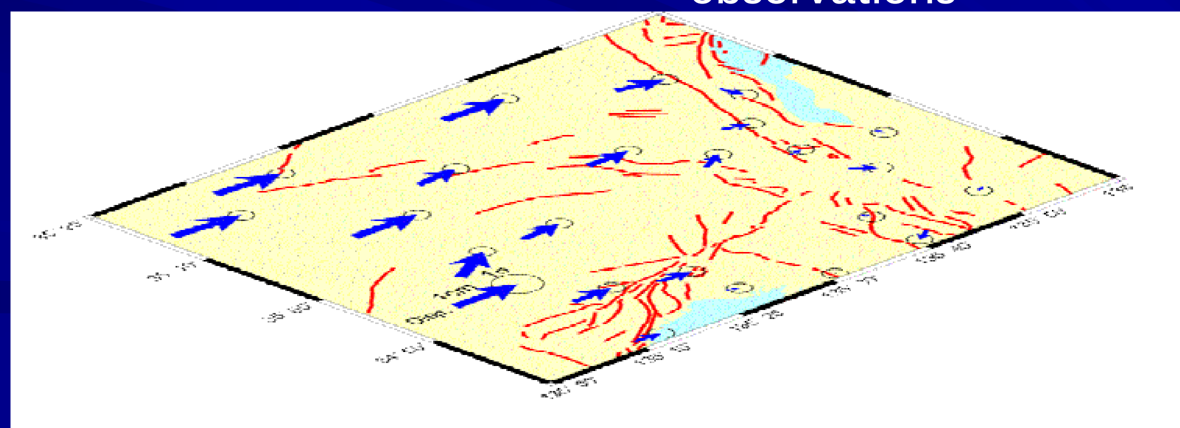


Detection of slow slip from continuous observations

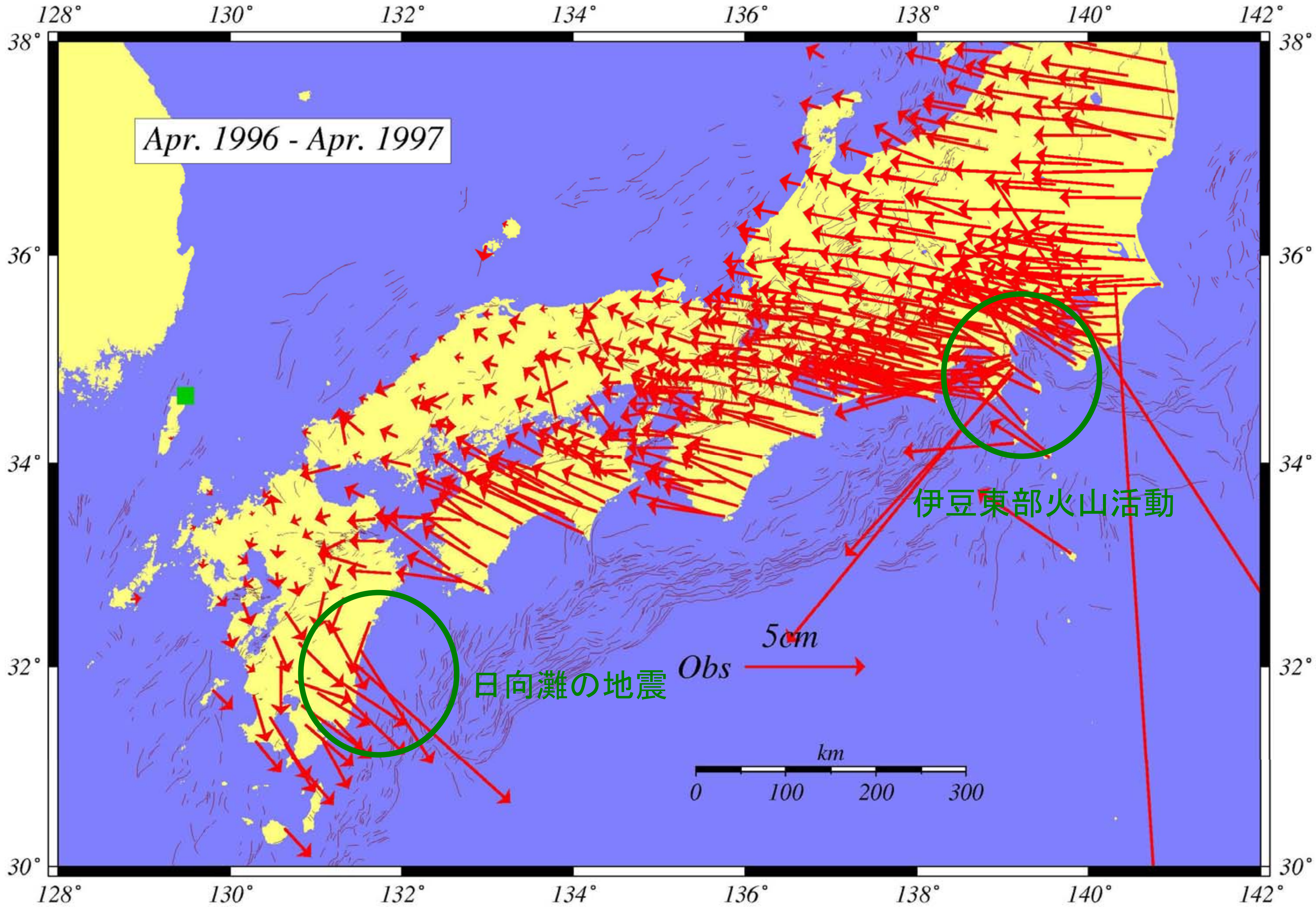
Inversion

Estimate of static fault parameters

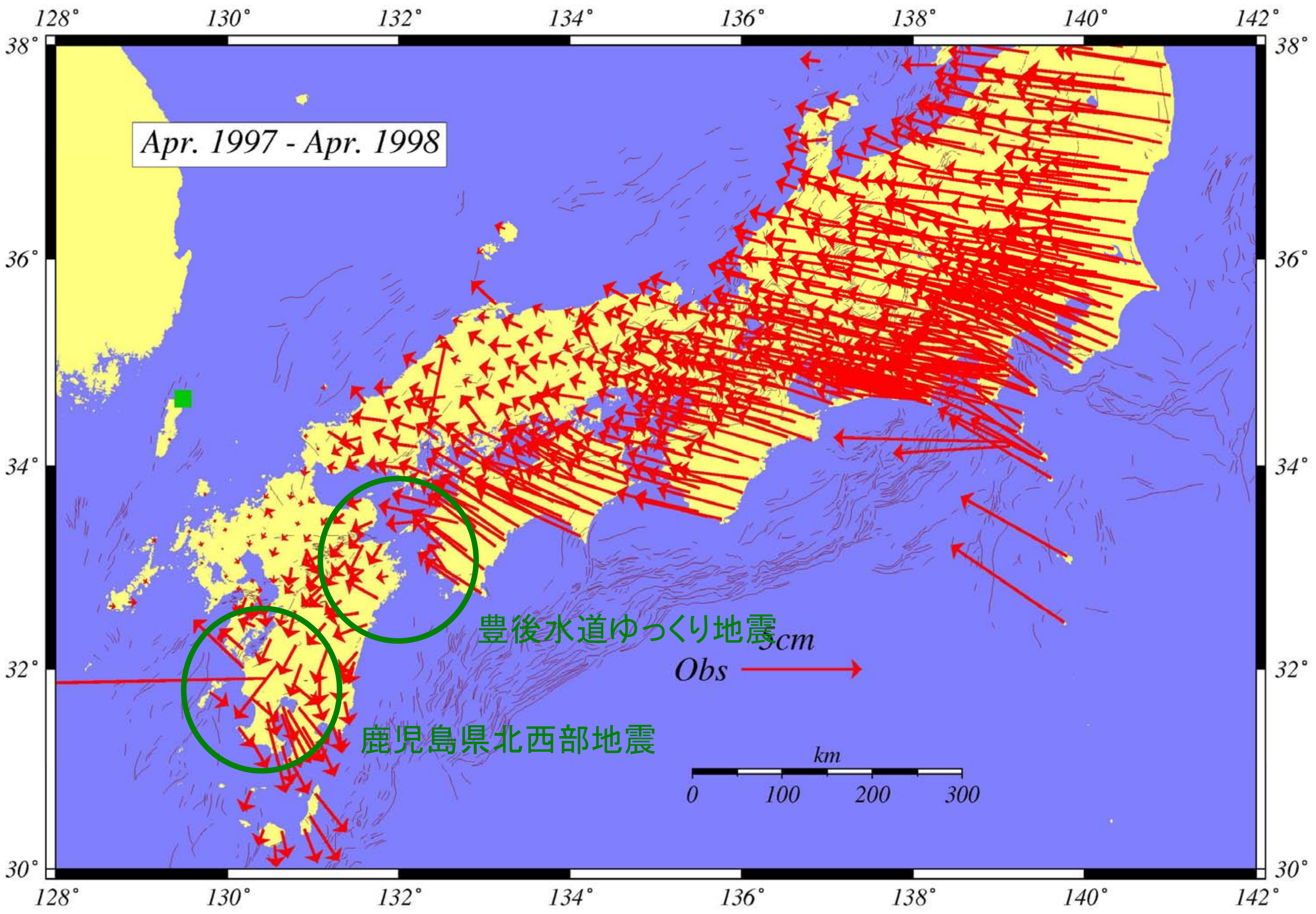
Detection of slow slip



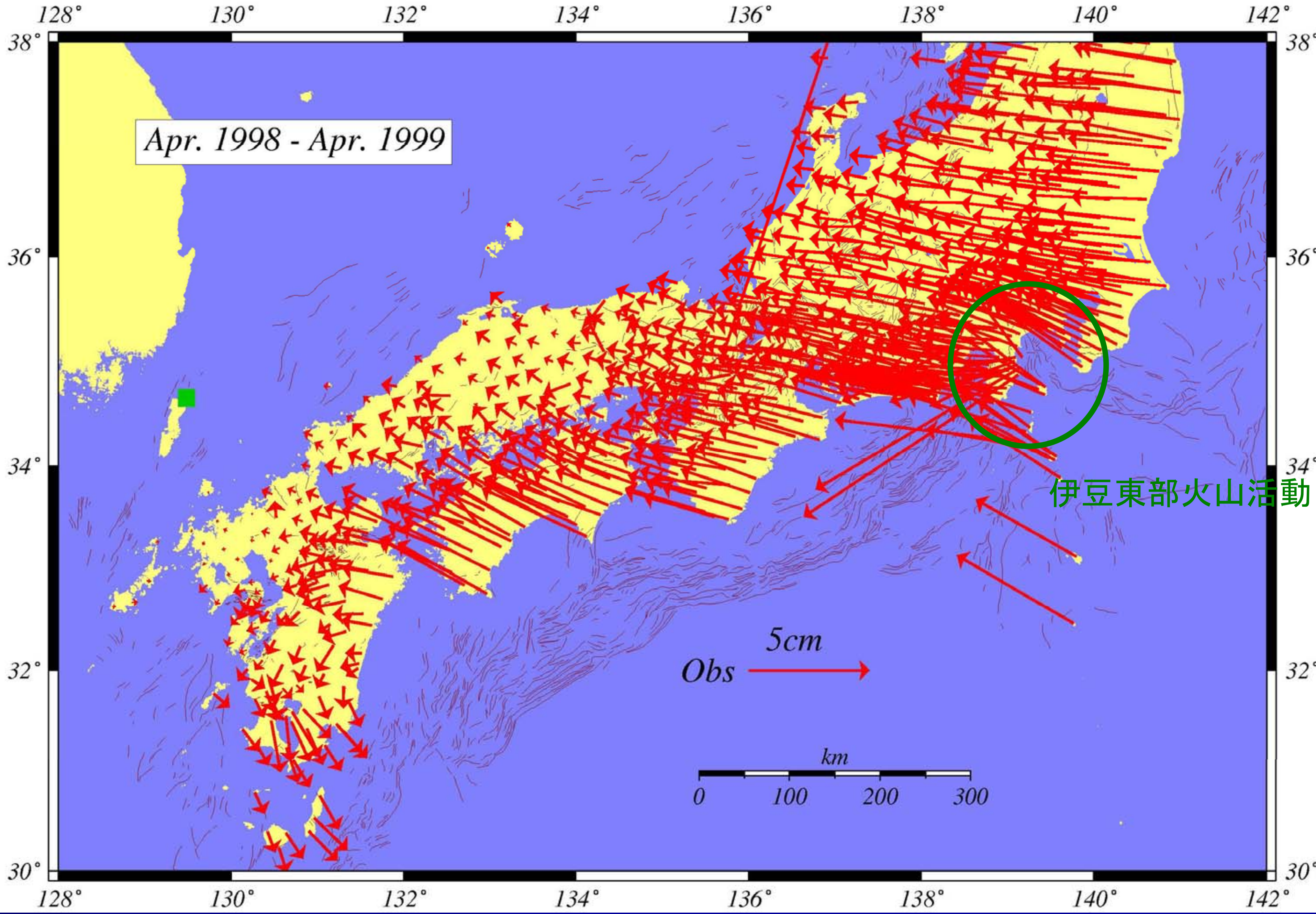
GPS velocity field



Apr. 1996 - Apr. 1997
伊豆東部火山活動
日向灘の地震
5cm
Obs
km
0
100
200
300
128°
130°
132°
134°
136°
138°
140°
142°
38°
36°
34°
32°
30°



Apr. 1997 - Apr. 1998
128°
130°
132°
134°
136°
138°
140°
142°
38°
36°
34°
32°
30°
豊後水道ゆっくり地震
鹿児島県北西部地震
5cm
Obs
km
0
100
200
300



Apr. 1998 - Apr. 1999
5cm
Obs
km
0
100
200
300
伊豆東部火山活動
128°
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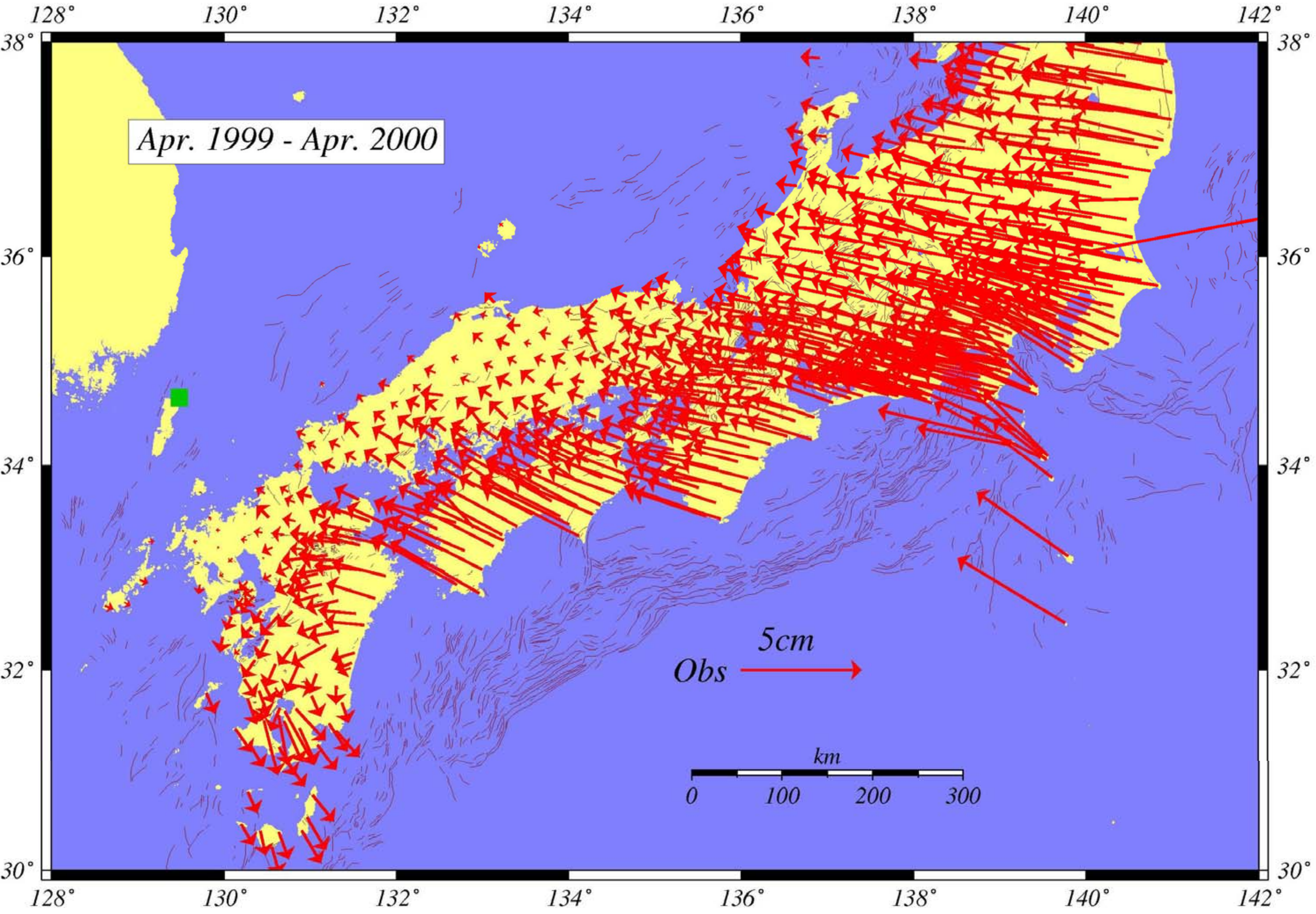
30°



Apr. 1999 - Apr. 2000
5cm
Obs
km
0
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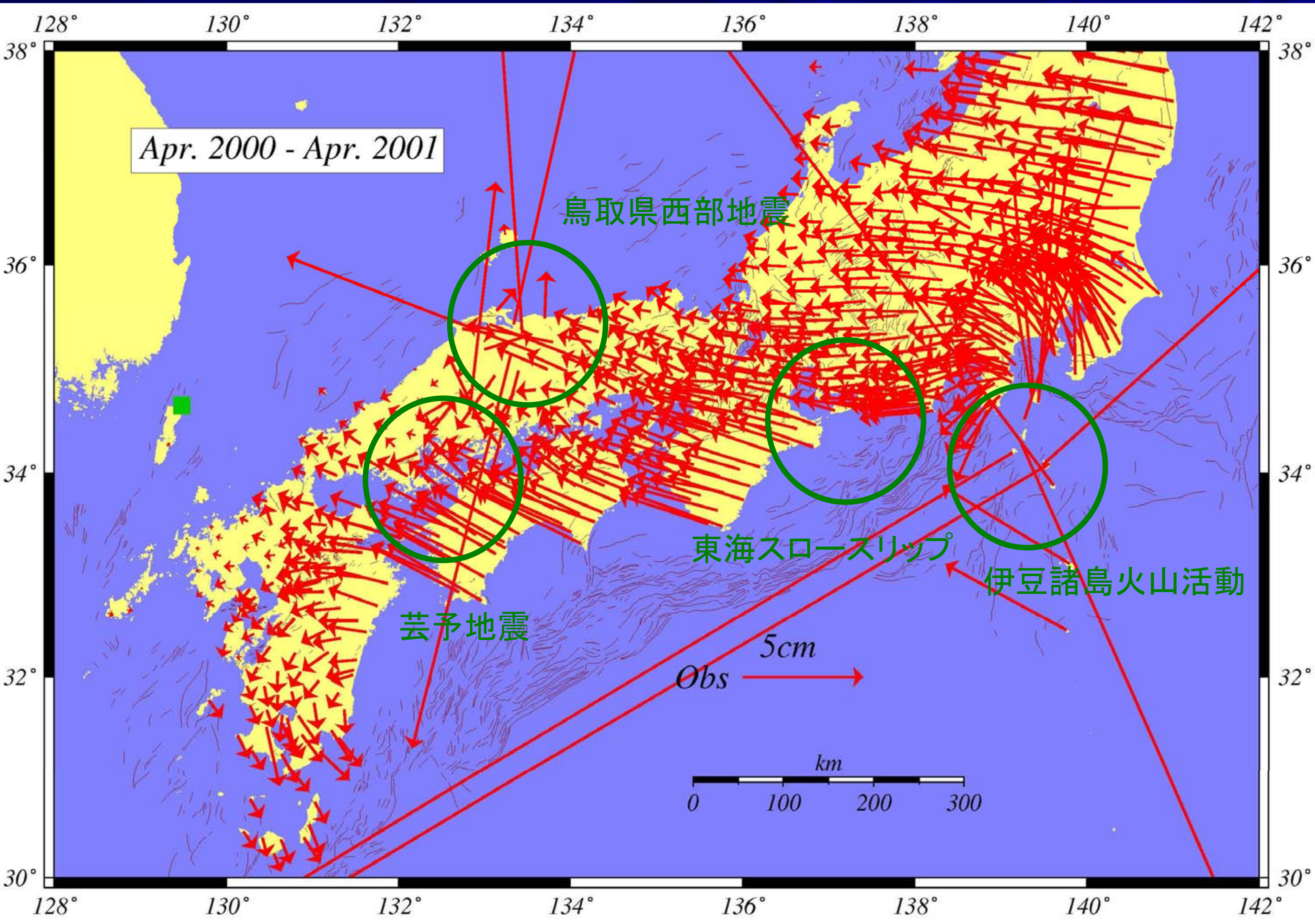
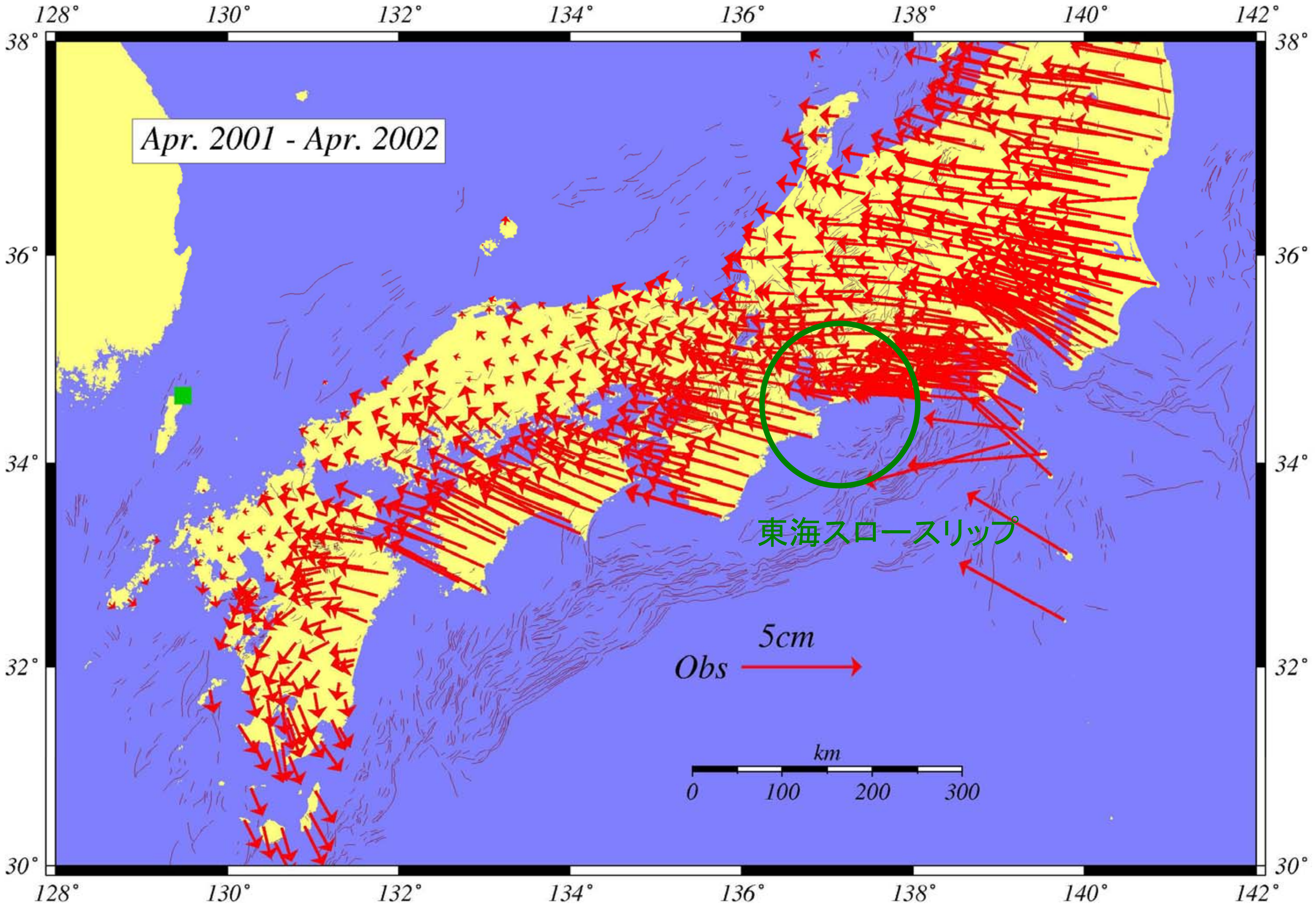


Apr. 2000 - Apr. 2001
鳥取県西部地震
芸予地震
東海スロースリップ
伊豆諸島火山活動
5cm
Obs
km
0
100
200
300
128°
130°
132°
134°
136°
138°
140°
142°
38°
36°
34°
32°
30°


Apr. 2001 - Apr. 2002
東海スロースリップ
5cm
Obs
km
0
100
200
300
128°
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134°
136°
138°
140°
142°
38°
36°
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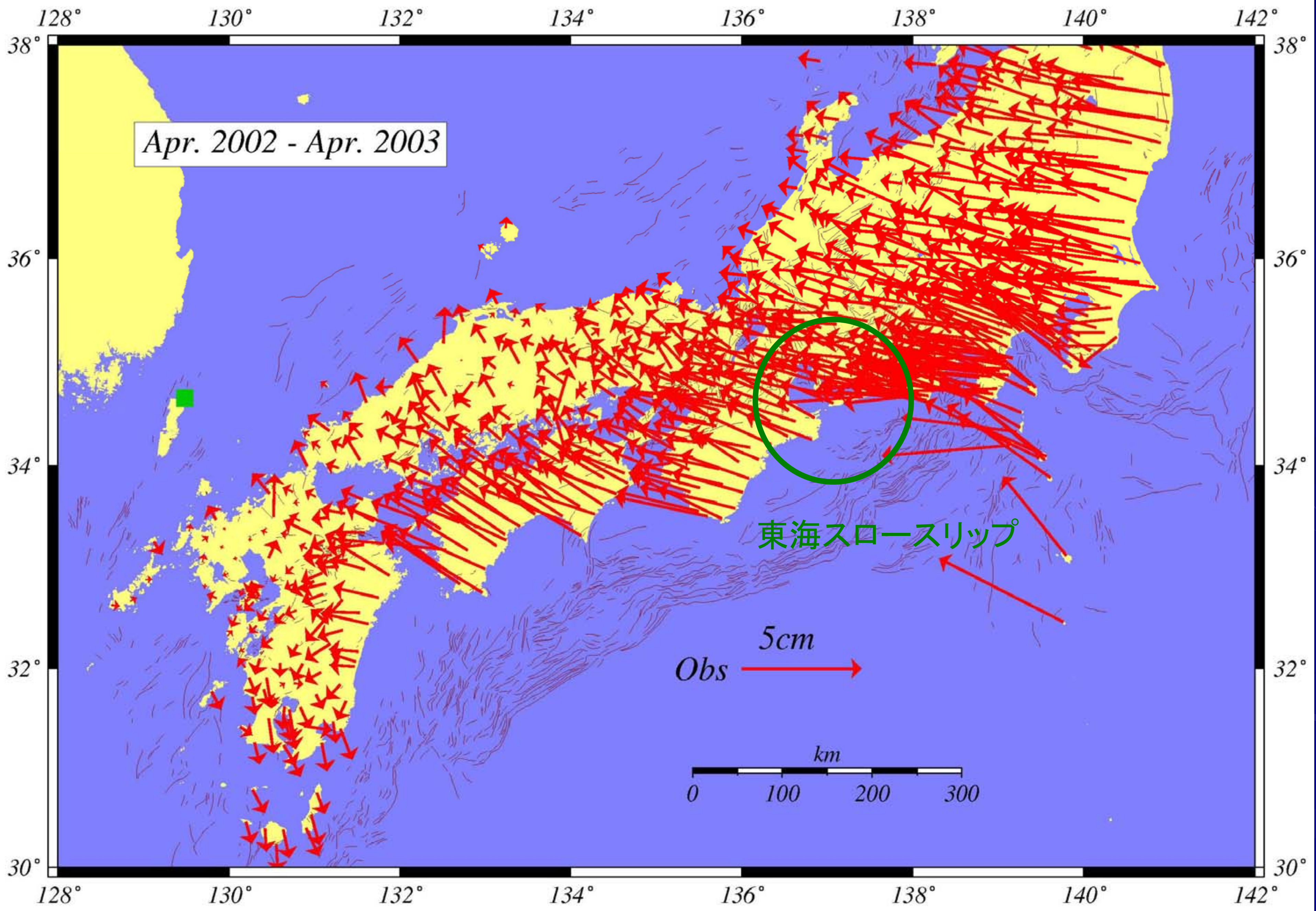
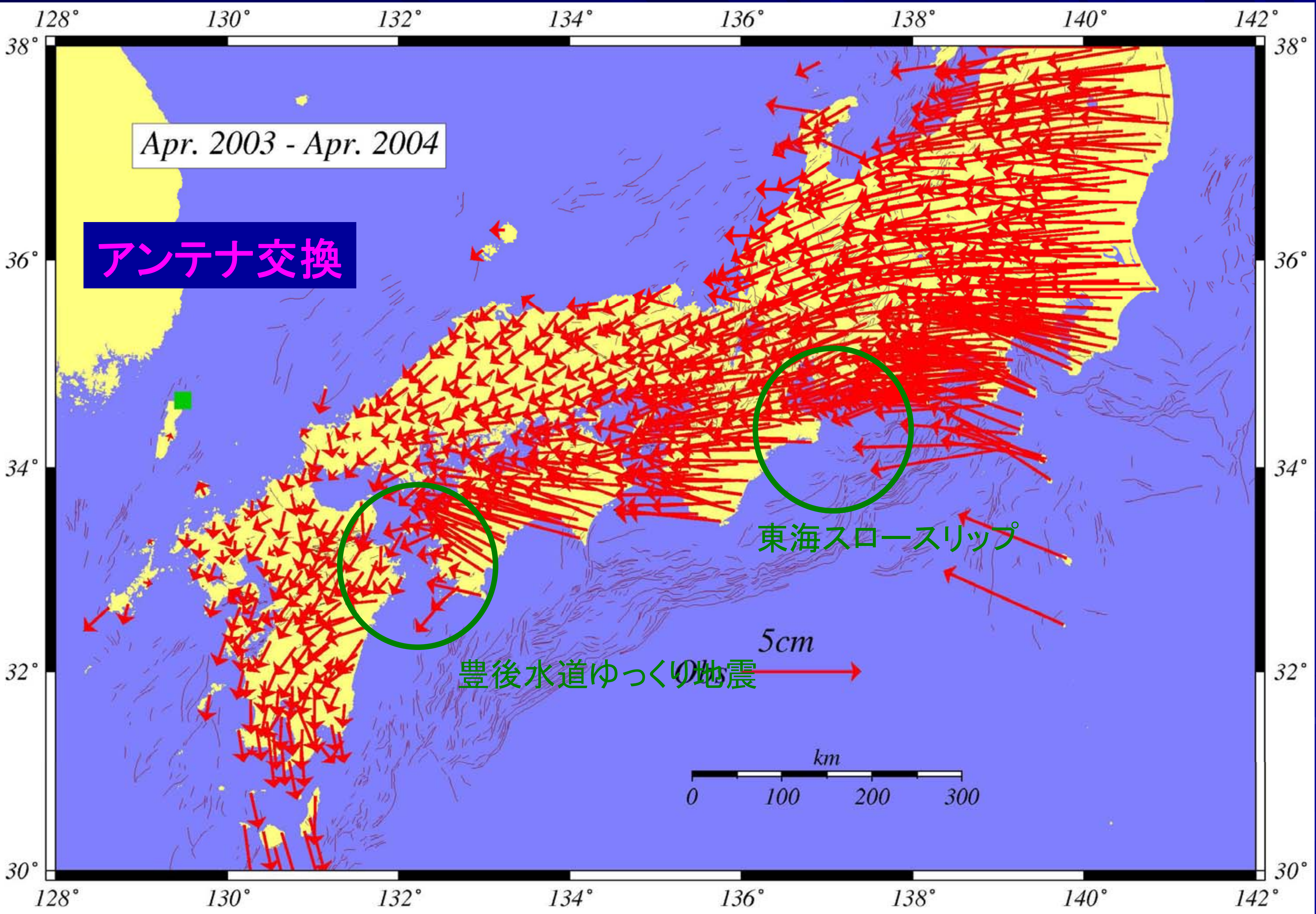
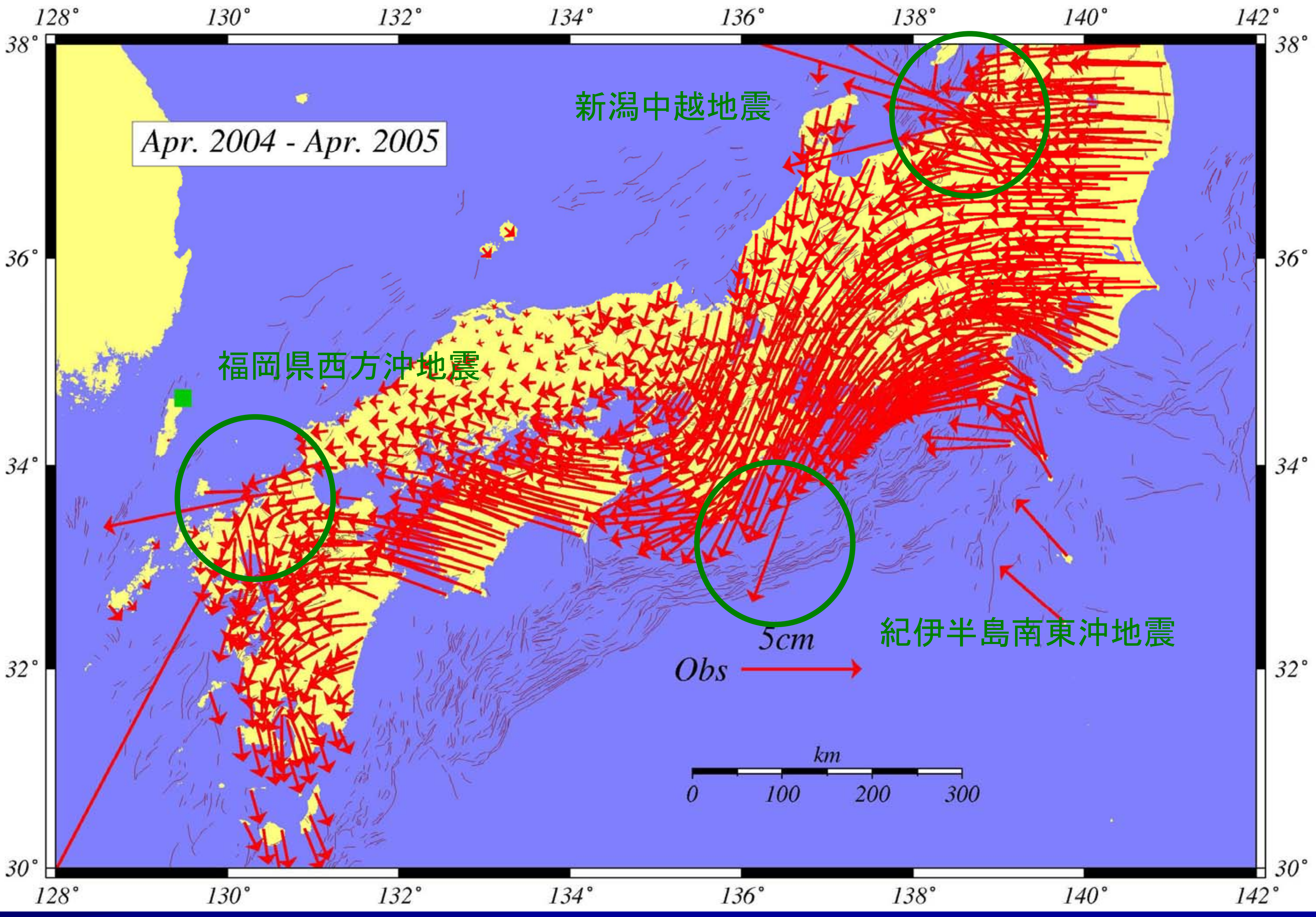
32°
30°



Apr. 2002 - Apr. 2003
東海スロースリップ
5cm
Obs
km
0
100
200
300
128°
130°
132°
134°
136°
138°
140°
142°
38°
36°
34°
32°
30°



Apr. 2003 - Apr. 2004
アンテナ交換
東海スロースリップ
豊後水道ゆっくり地震
5cm
Obs
km
0
100
200
300
128°
130°
132°
134°
136°
138°
140°
142°
38°
36°
34°
32°
30°



Apr. 2004 - Apr. 2005
新潟中越地震
福岡県西方沖地震
紀伊半島南東沖地震
5cm
Obs
km
0
100
200
300
128°
130°
132°
134°
136°
138°
140°
142°
38°
36°
34°
32°
30°

Limit of Present Studies

- Problems on the observational side
  – Limited spatial resolution
  – Limited resources (man power, equipment etc.)
- Problems on the theoretical side
  – Green's function in heterogeneous structures

Characteristics of C-GPS

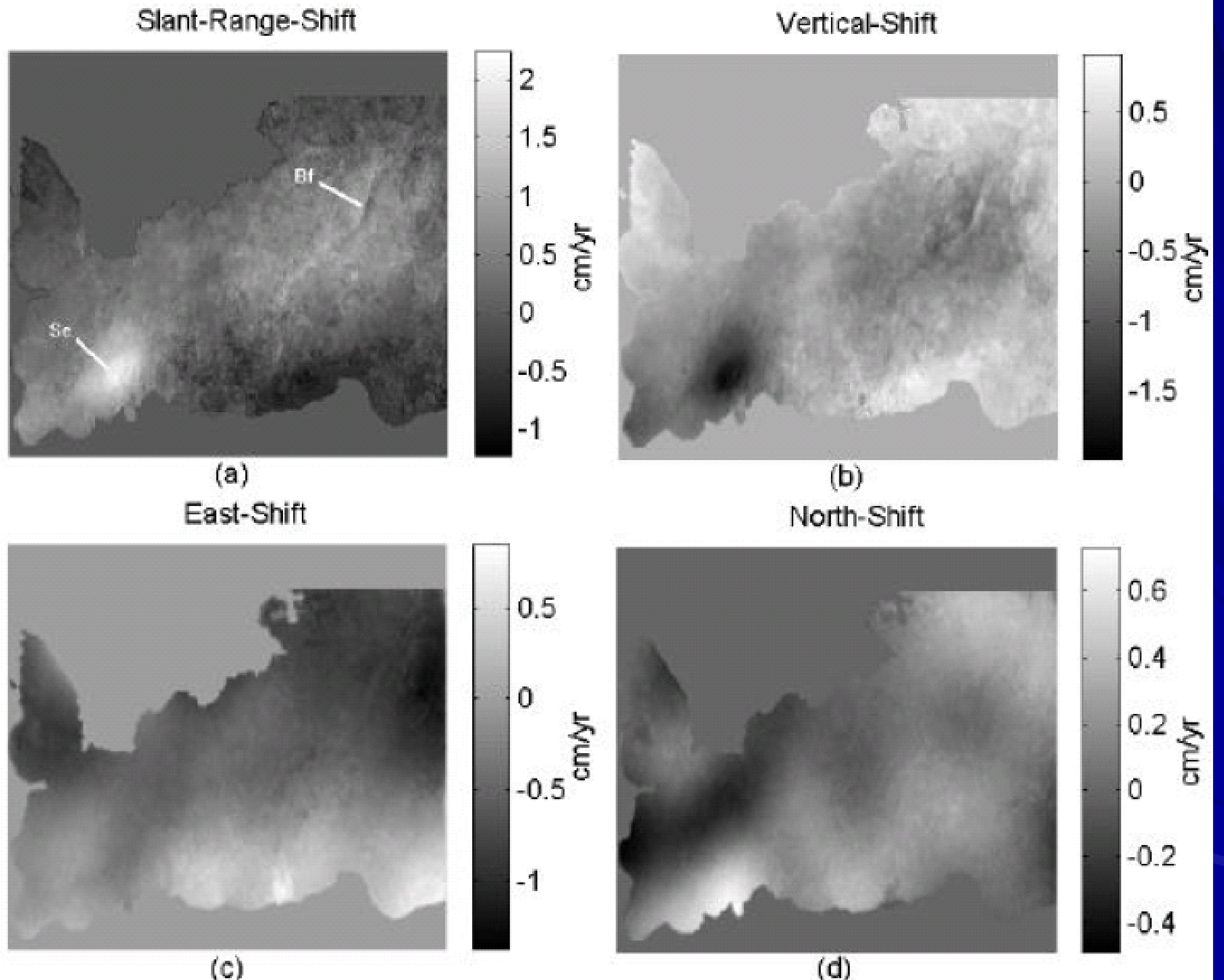
- Advantage
  - Temporal high resolution
  - Wide areal coverage
  - 3 component observation
  - High accuracy
    - Horizontal ~2-3mm
    - Vertical >~5mm
- Disadvantage
  - Low spatial resolution
  - Occupations & equipments required

Characteristics of InSAR

- Advantage
  - High spatial resolution
  - No fieldwork or special equipment
- Disadvantage
  - One component (Line of Sight) observation
  - Less temporal resolution
  - Limited areal coverage

Collaboration of InSAR and GPS

- Essential to combine observed displacements by InSAR and GPS
  - Complement of advantages of both techniques
- Requirements
  - Development of analysis techniques
  - Selection of suitable fields



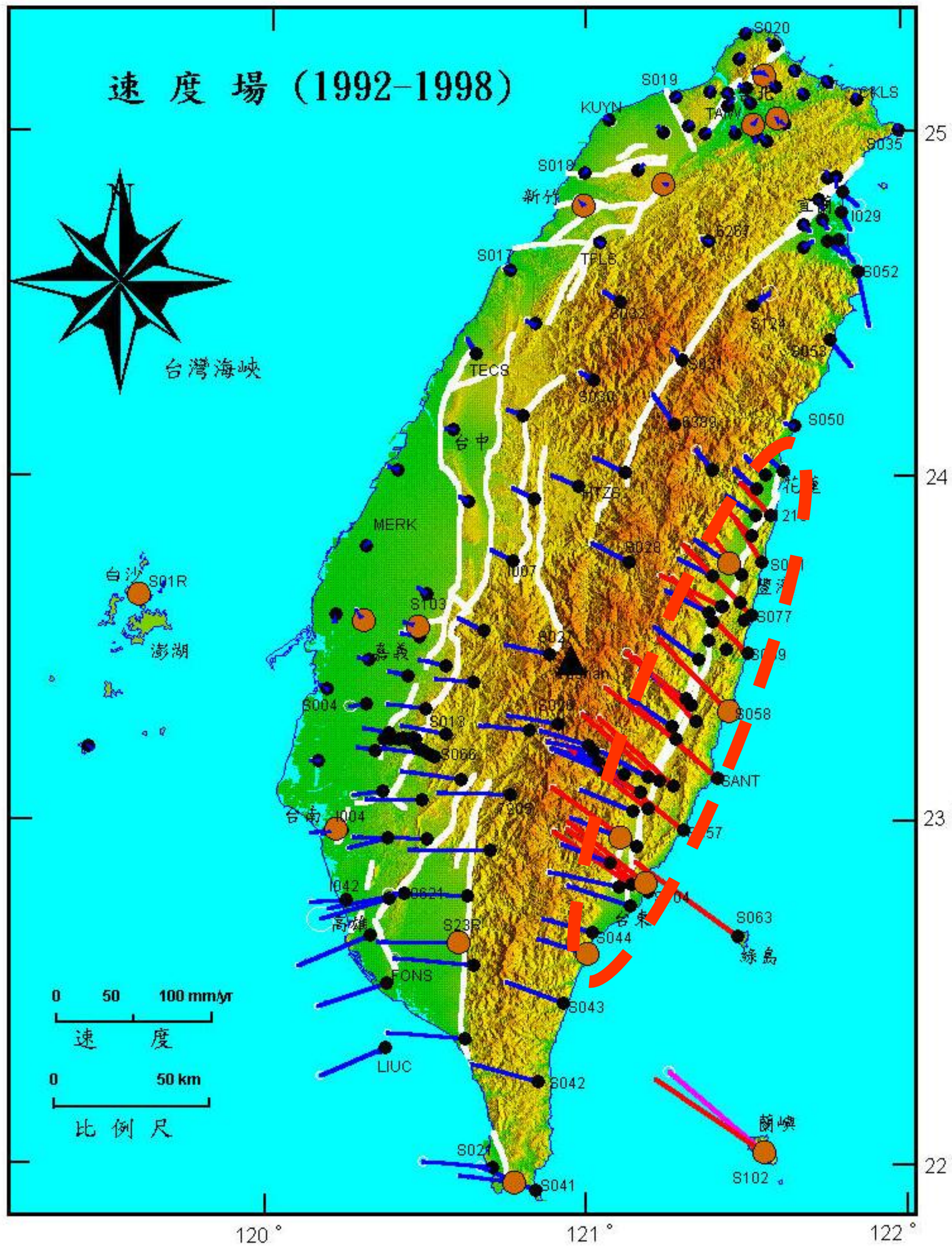
Bh: Bláfjallahryggur.
Se: Svartsengi.

Gudmundsson (2000)

Example of Observed Creep Displacements by InSAR

GPS Velocity Field in Taiwan

- Plate boundary on land
- Collision between Philippine Sea and continental plates



By Shui-Bei Yu

Longitudinal Valley, Taiwan

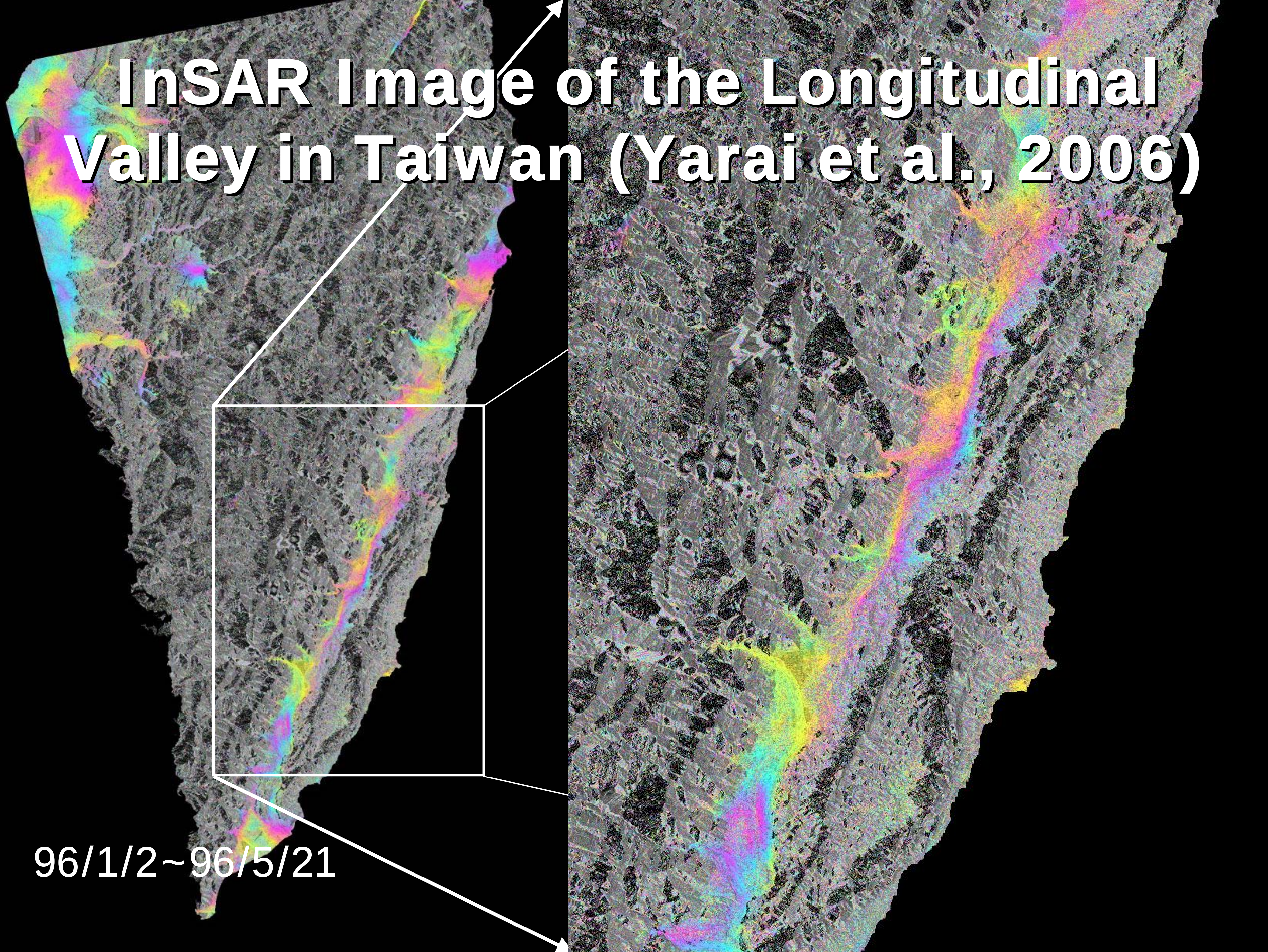
- 150km long valley trending N-S between Hualian ~ Taitung
- Coastal range in the east, Central range in the west

Central Range Coastal Range

Deformation of the Northern Bank due to Fault Creep

Deforming Concrete Pipe

InSAR Image of the Longitudinal Valley in Taiwan (Yarai et al., 2006)



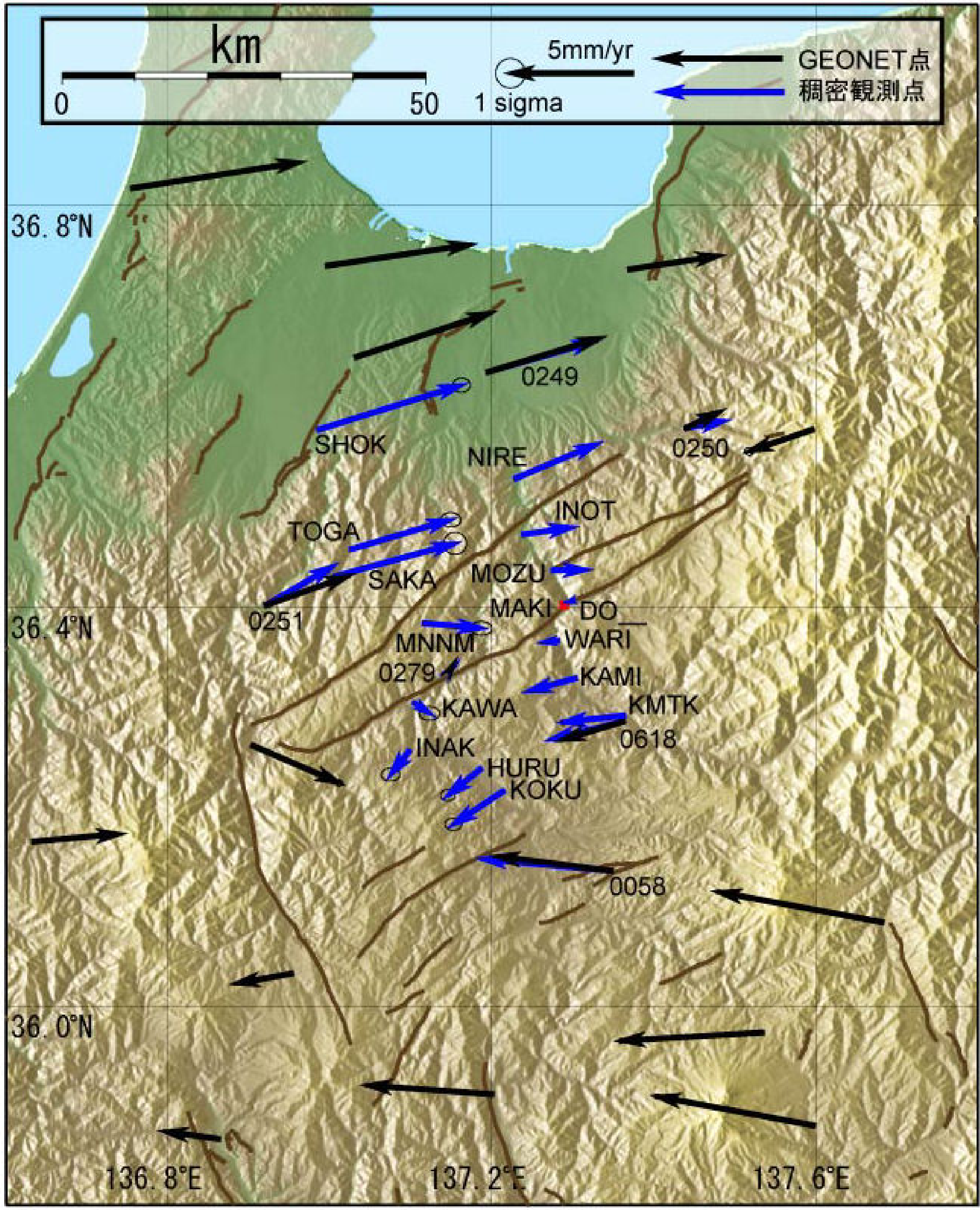
So, we can do it!
It's time to do it!
We have interesting field in Japan!

Active Faults

Atotsugawa, Yamasaki etc.

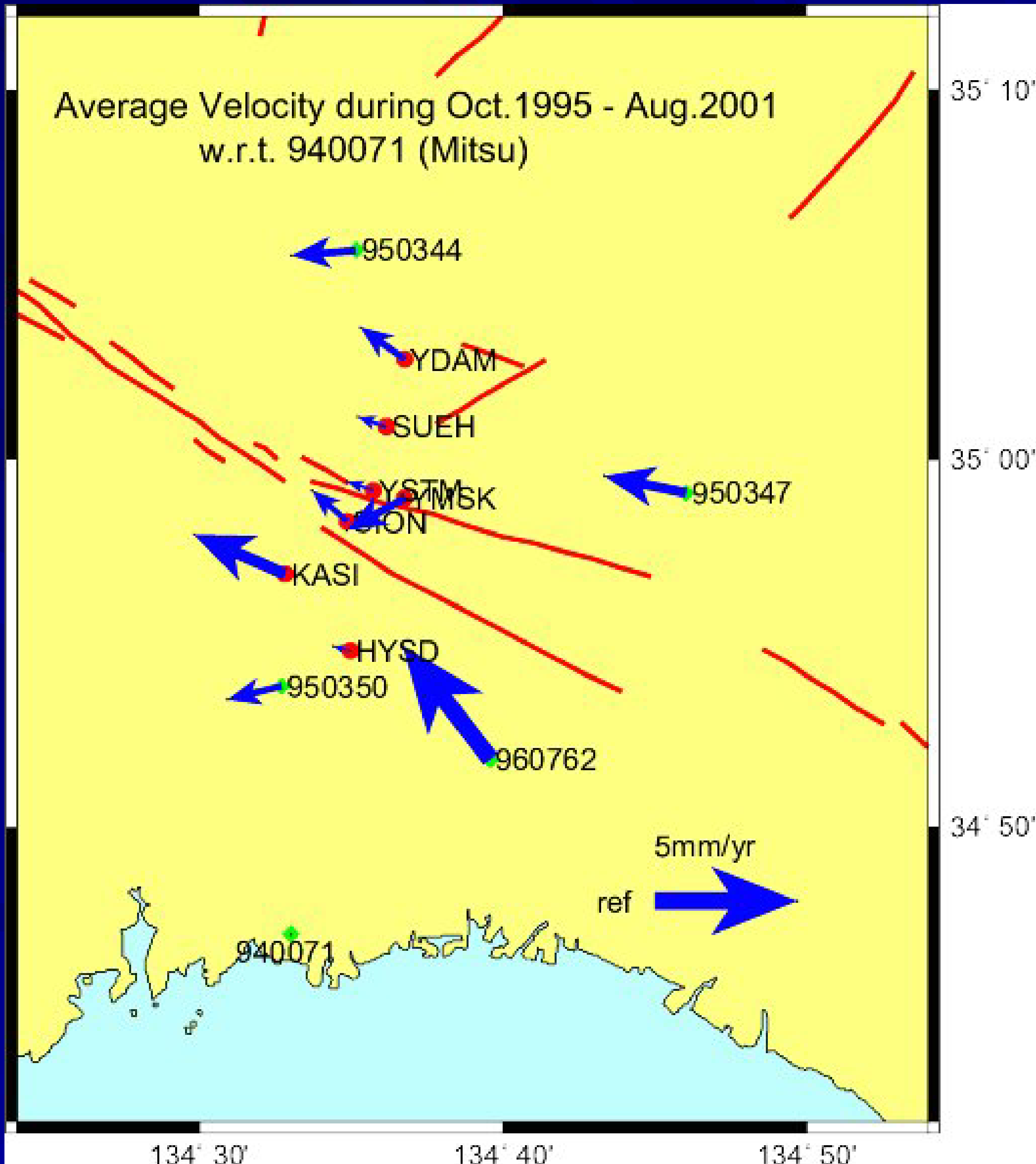
GPS Velocity Field Around the Atotsugawa Fault (Oozono et al., 2006)

- Heterogeneous velocity field around the fault
- No creep?
- Density of GPS sites is not enough!
- Much higher spatial resolution is desired!



GPS Velocity Field Around the Yamaskai Fault

- Heterogeneous velocity field around the fault
- Only one profile perpendicular to the fault
- InSAR is necessary to reveal spatial distribution of velocity field.
- Stacking technique is required to detect small displacements

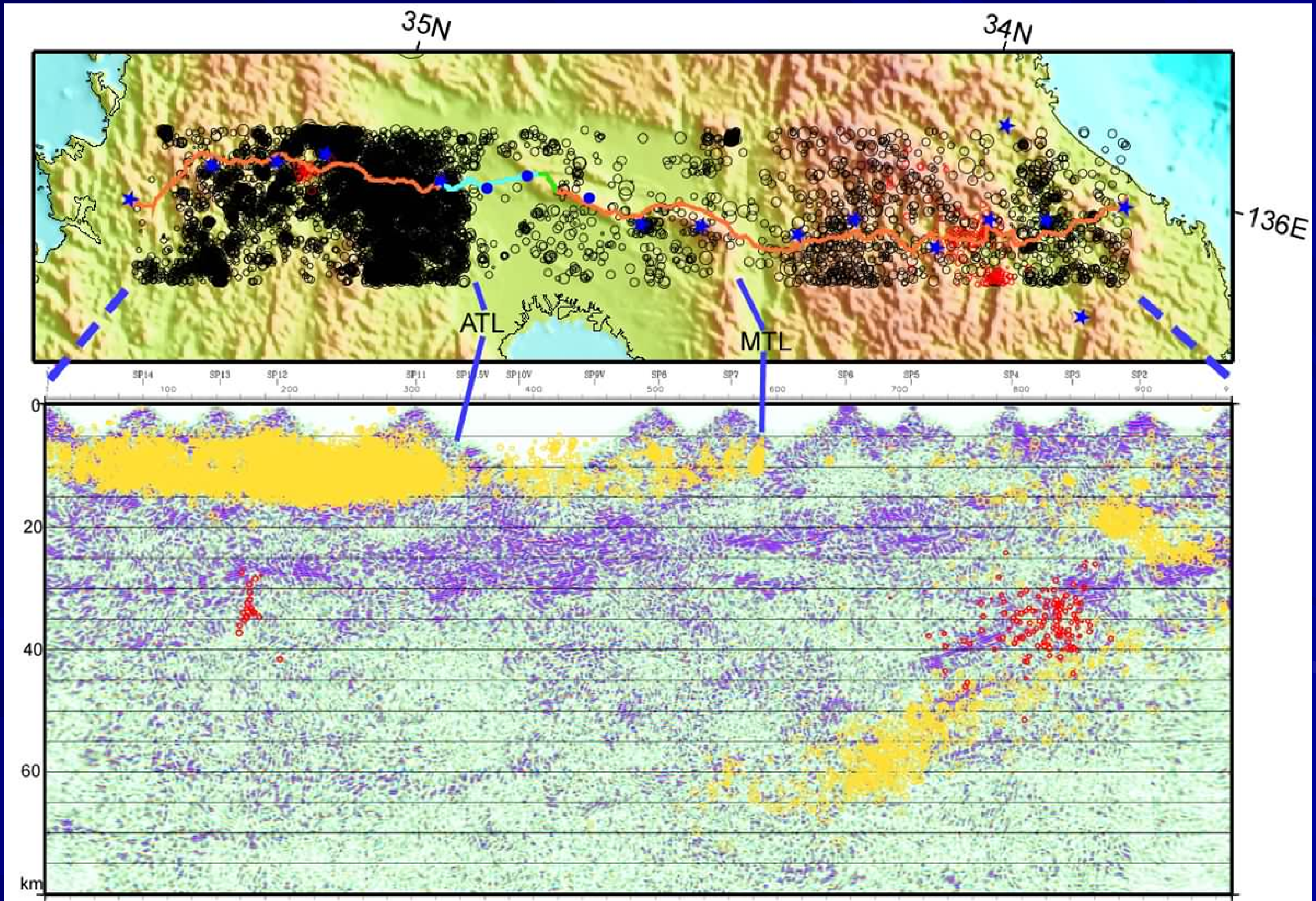


Can InSAR Contribute to the Research on Interplate EQ?

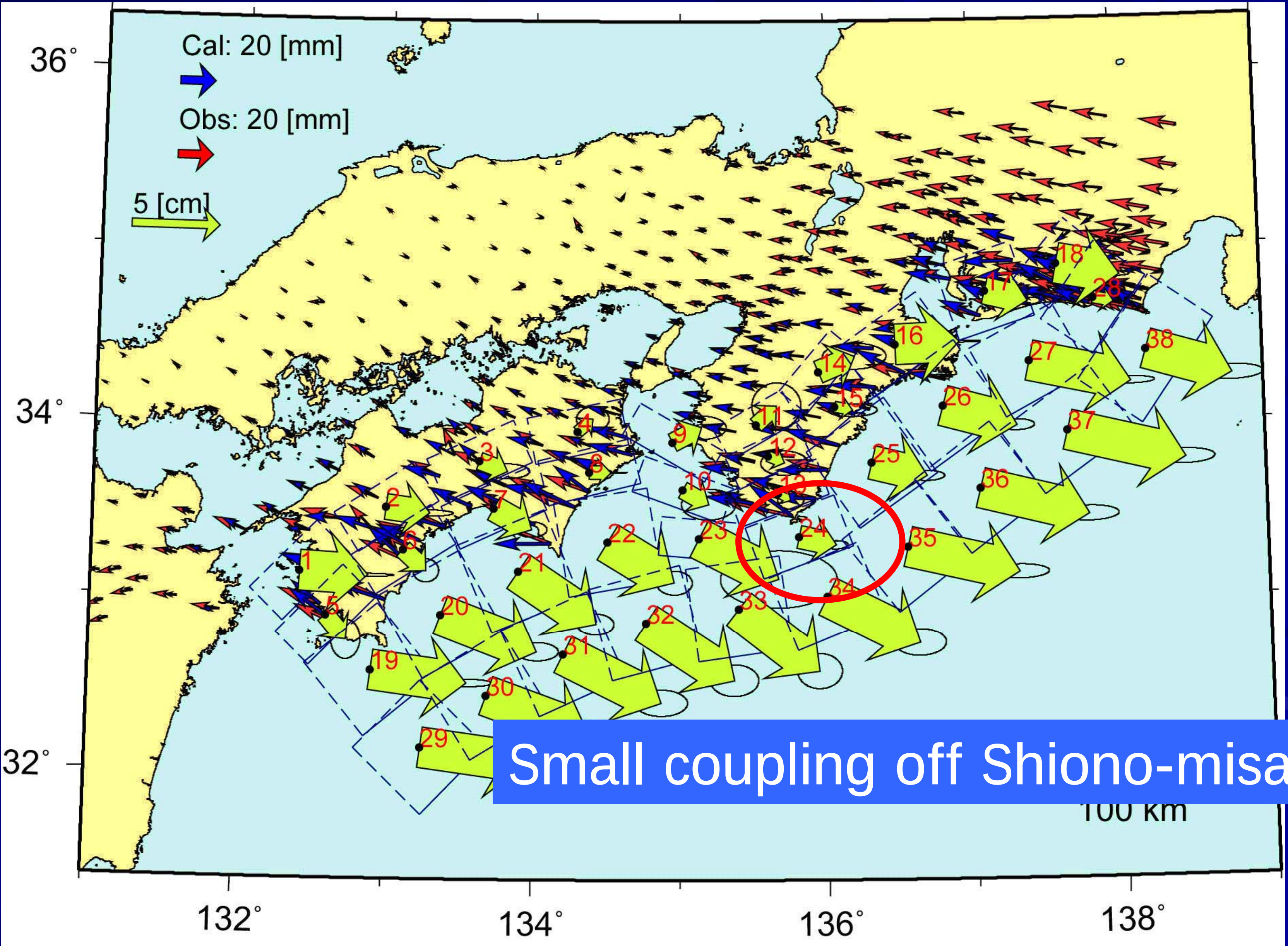
Yes!

There are several issues in which InSAR should play an important role.

Result of Refraction Survey Across the Kinki District: Shingu – Maizuru (Ito et al., 2005)

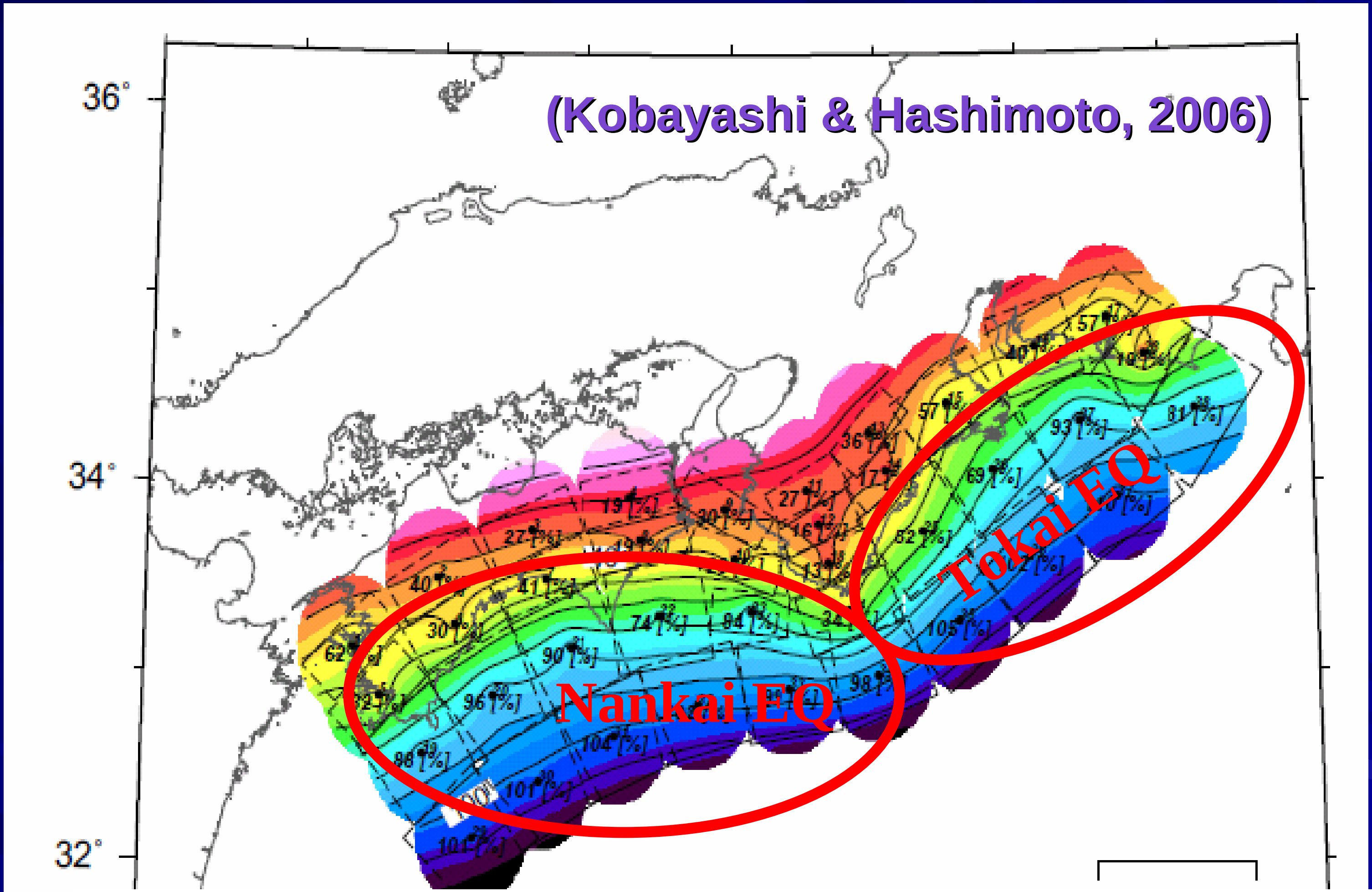


Distribution of Slip Deficit Rates Along the Nankai Trough (Kobayashi & Hashimoto, 2006)



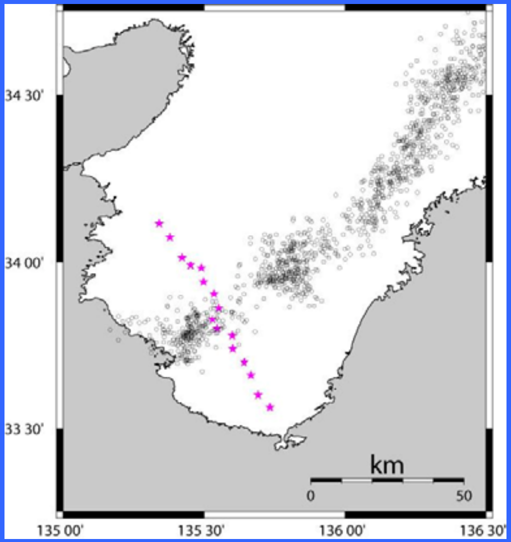
Small coupling off Shiono-misaki!

Distribution of Interplate Coupling Ratio Estimated From the GEONET Data

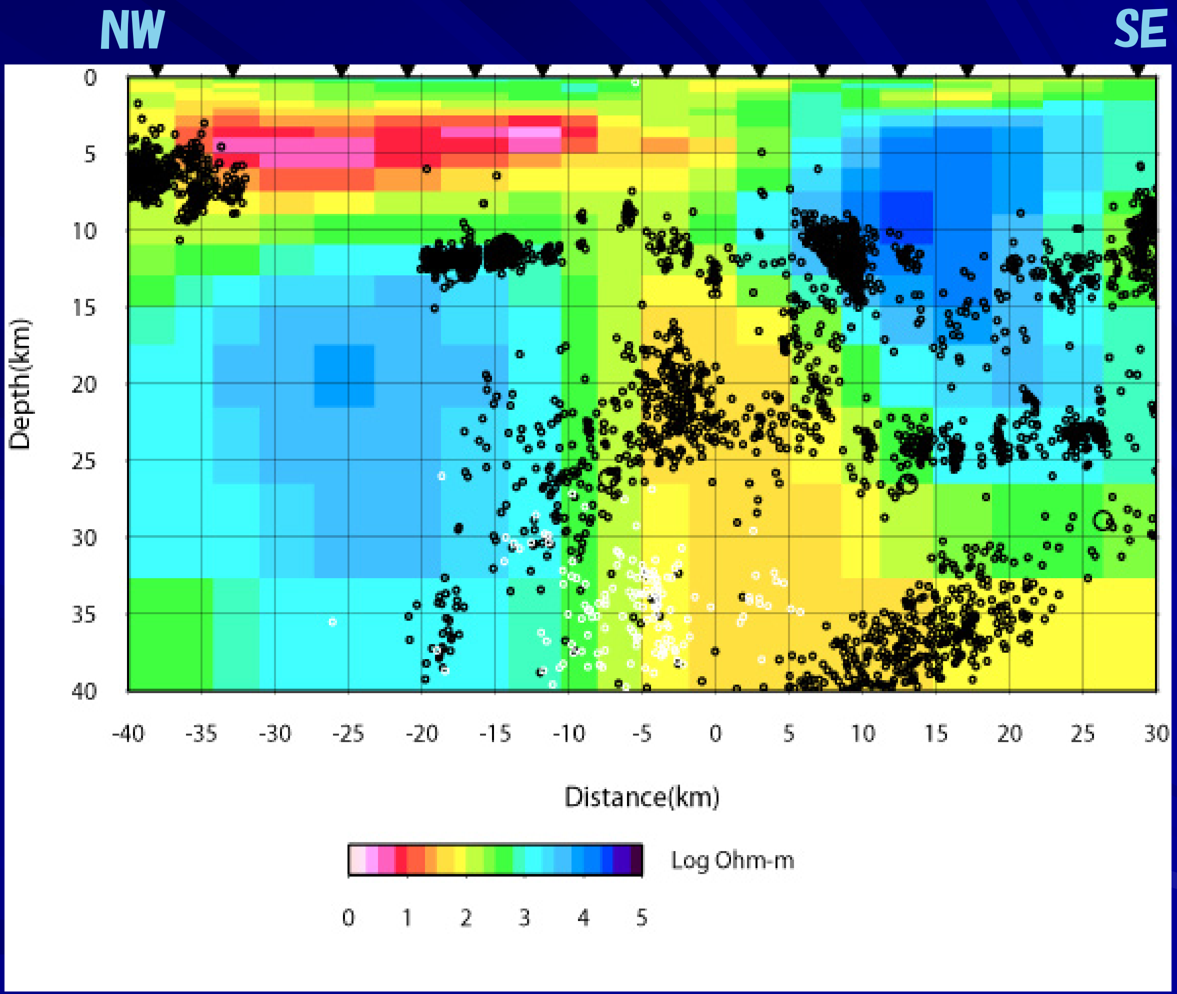


Source regions are separated off Kii Peninsula!?
Keypoint for linkage!

Conductivity Structure obtained by Wide Range MT

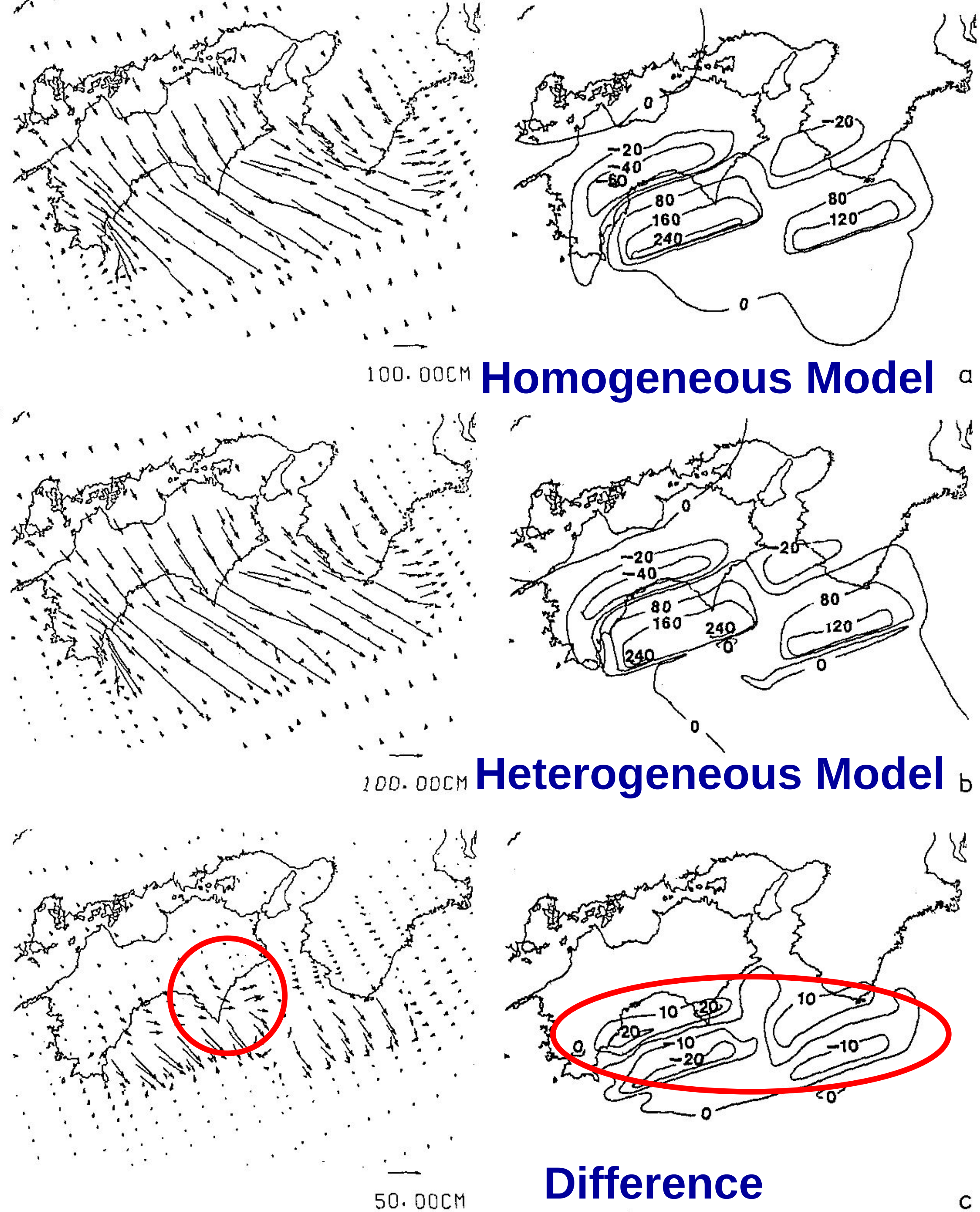


Distribution of observation sites and epicenters of DLF



Nagano et al.(2006)

White circles indicate hypocenters of deep low-frequency tremor.



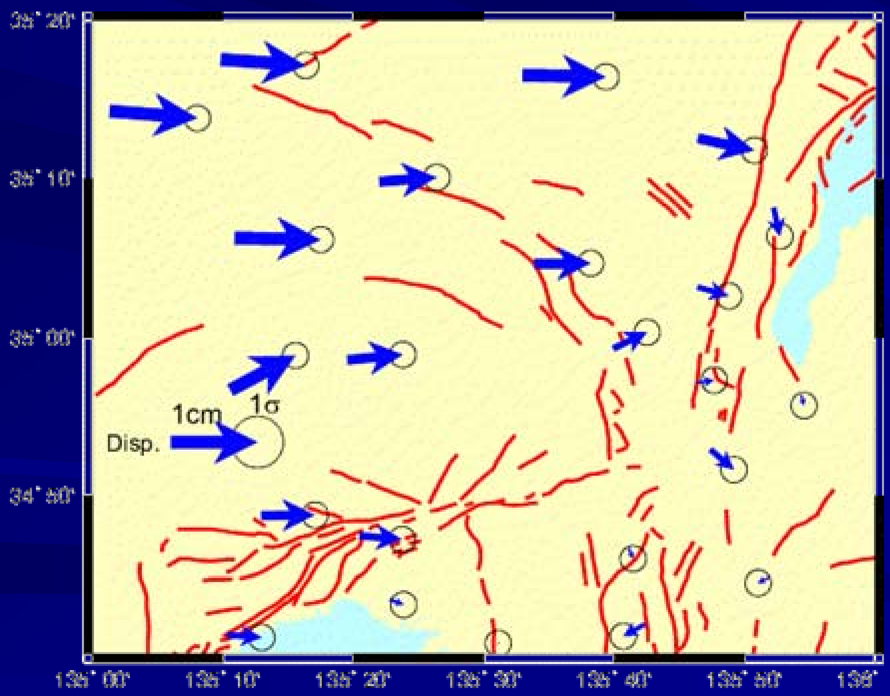
Results of the Calculation by Yoshioka et al.(1989)

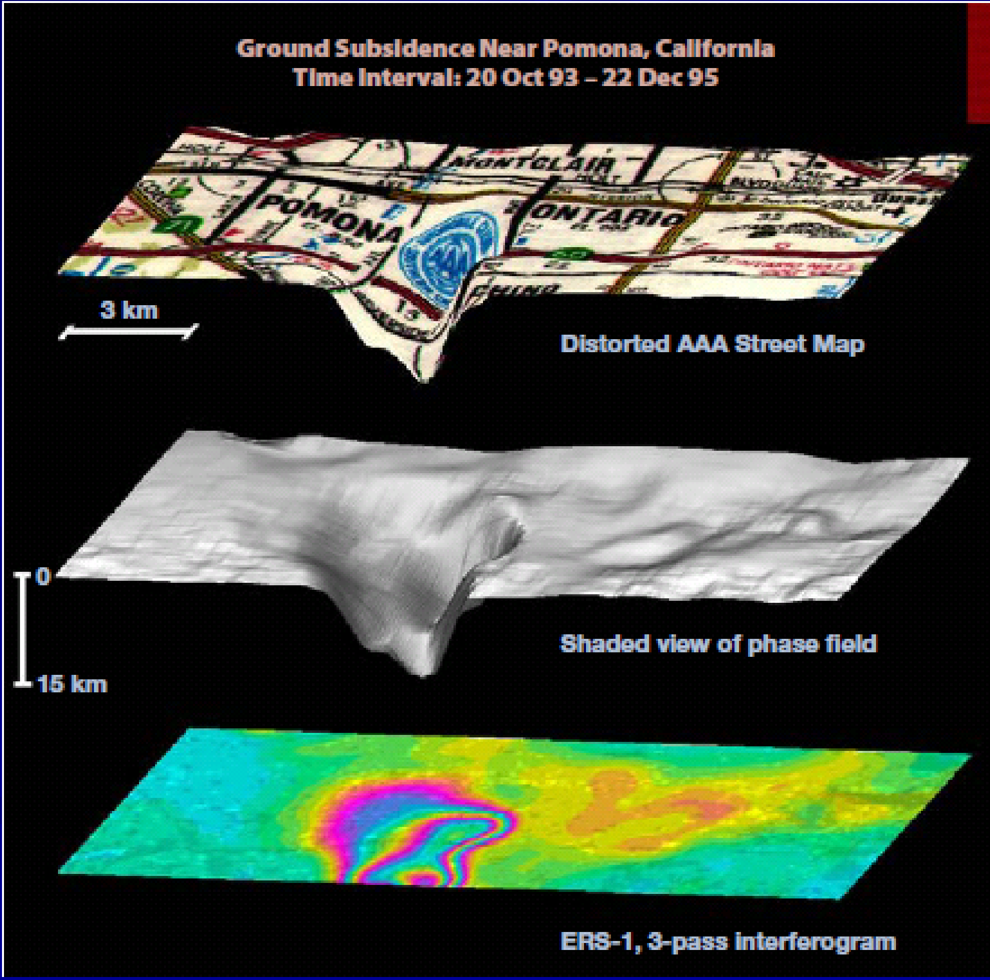
- Displacements are significantly different between two models.
- More dense data are required to resolve heterogeneity.

Discrimination of Signal and Noise in Velocity Field

Effect of Groundwater Level Changes

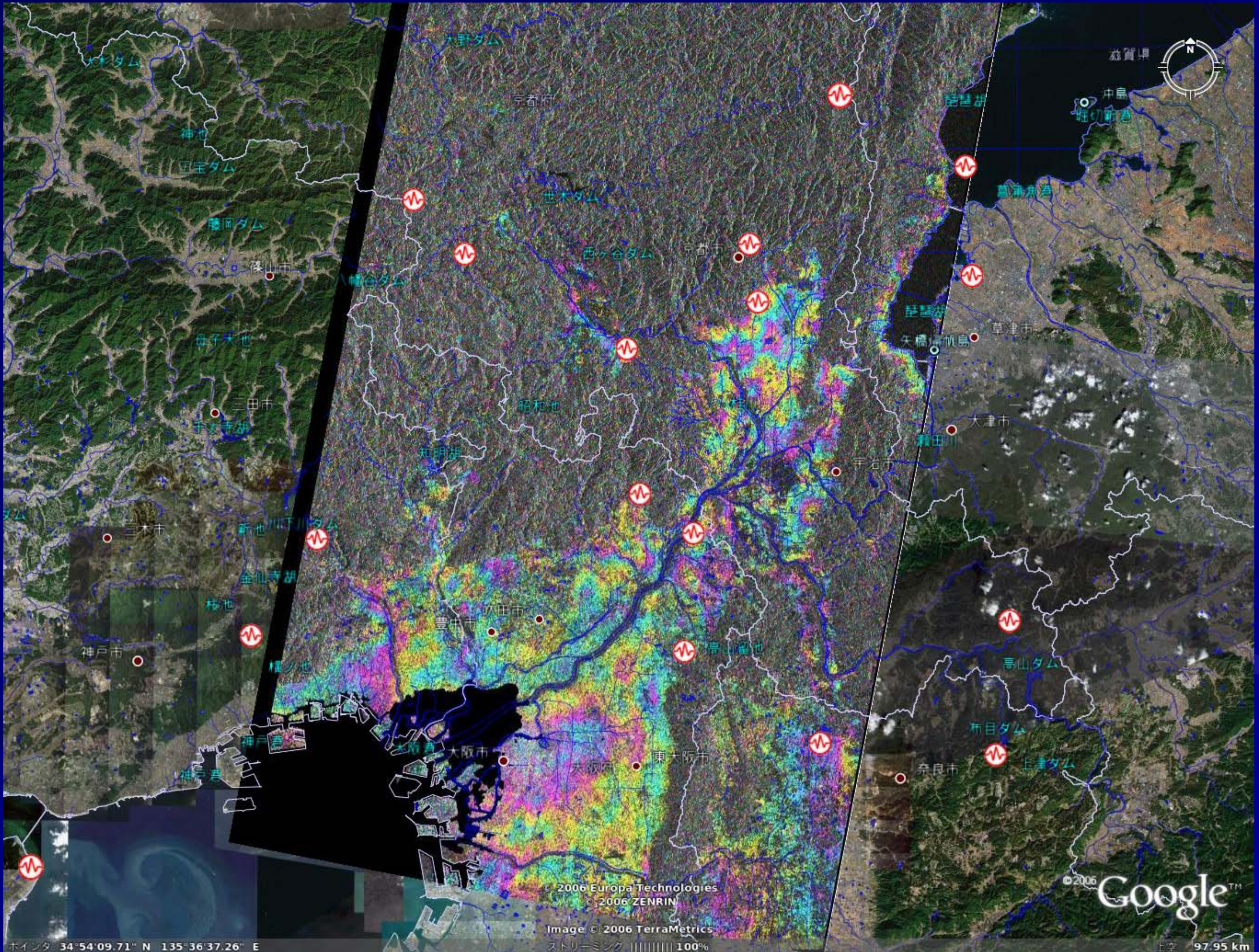
- Evaluation of effects of local subsidence on observed GPS velocities





InSAR Workshop Summary Report (2004)

InSAR Image Obtained by RADARSAT (Fukushima, 2006)



Summary

- InSAR should play a key role in the study of strain accumulation process.
  - High spatial resolution
- Necessary development in InSAR
  - L-Band
  - Stacking/PS-InSAR
- Combination with GPS is essential.
  - To interpolate 3-D displacement/velocity field
  - To evaluate the effect of heterogeneity of crust
  - To check the stability of GPS sites
- Targets
  - Active faults: Atotsugawa, Yamasaki, Kinki etc.
  - Subduction zones: Kii peninsula, Hyuganada etc.