Earthquakes triggered by the solid earth tide

Ling-Yun Chang

Reference

- Tanaka, S., M. Ohtake, and H. Sato, Tidal triggering of earthquakes in Japan related to the regional tectonic stress, *Earth Planets Space*, **56**,511-515, 2004.

- Ross S. Stein, Tidal triggering caught in the act, *Science*, **305**, 1248-1249, 2004.

- Tanaka, S., M. Ohtake, and H. Sato, Evidence for tidal triggering of earthquakes as revealed from statistical analysis of global data, *J. Geophys. Res.*, **107**(B10), 2211, doi:10.1029/2001JB001577, 2002b.

Introduction

- Tidal stress change is much smaller (10^3 Pa) than the typical stress drop of earthquakes, but its rate is generally larger than that of tectonic stress accumulation.
- Many studies : focal mechanism, tensor of confining stress.
- Tanaka *et al.* (2004) : we further explore the relation between the tidal effect on earthquake occurrence and the tectonic stress field (the direction of the tidal compressional stress).
- Although the result of Tanaka *et al.* (2004) seems good, the tidal effect is evident in only 13%. If we want to monitor earthquakes by tidal stress, there are many parameters must be checked.

DATA

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  Meteorologica
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- focal depth ≤
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- Dividing the
  subregions, w
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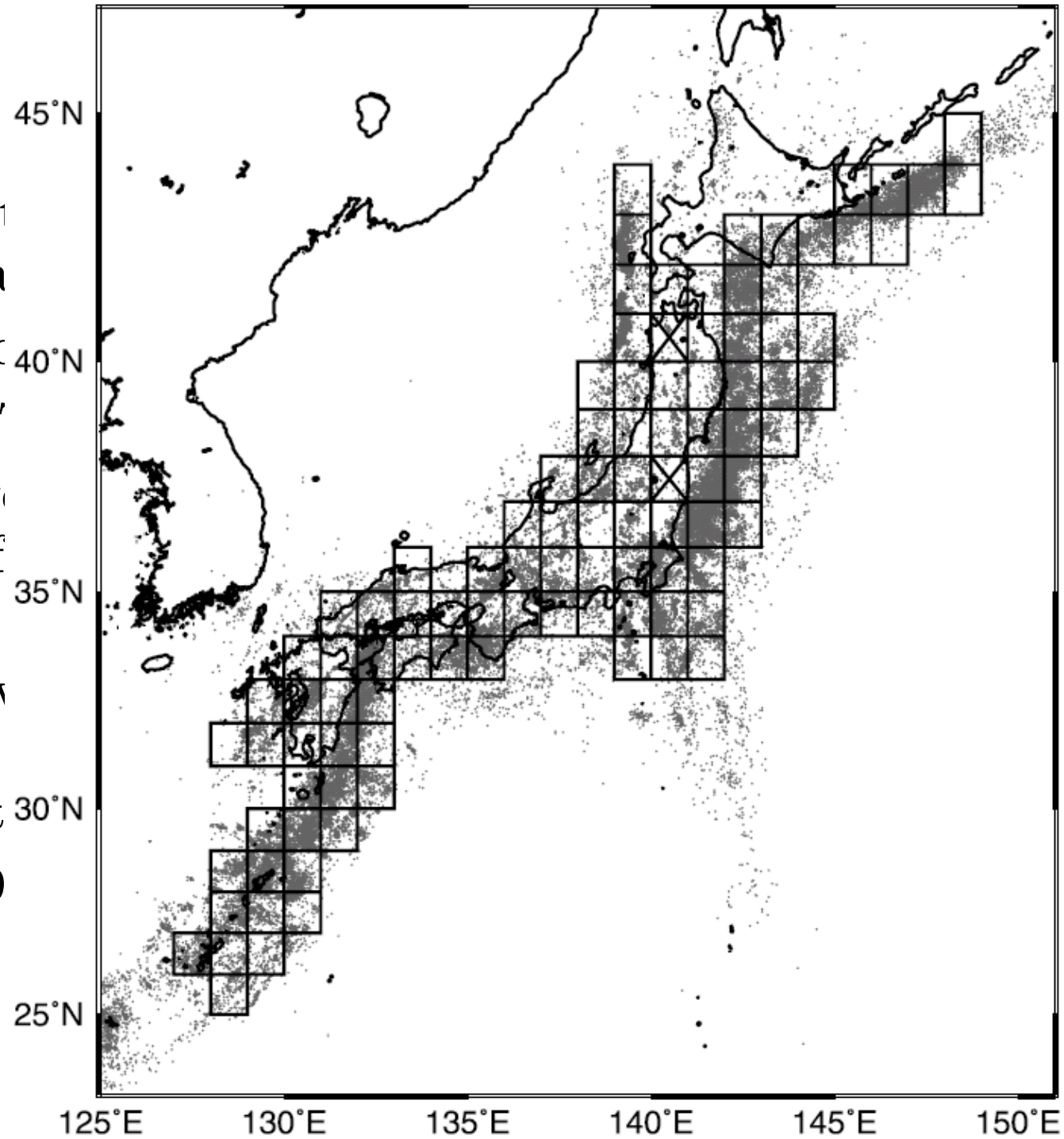
- A total of 89
  this study.



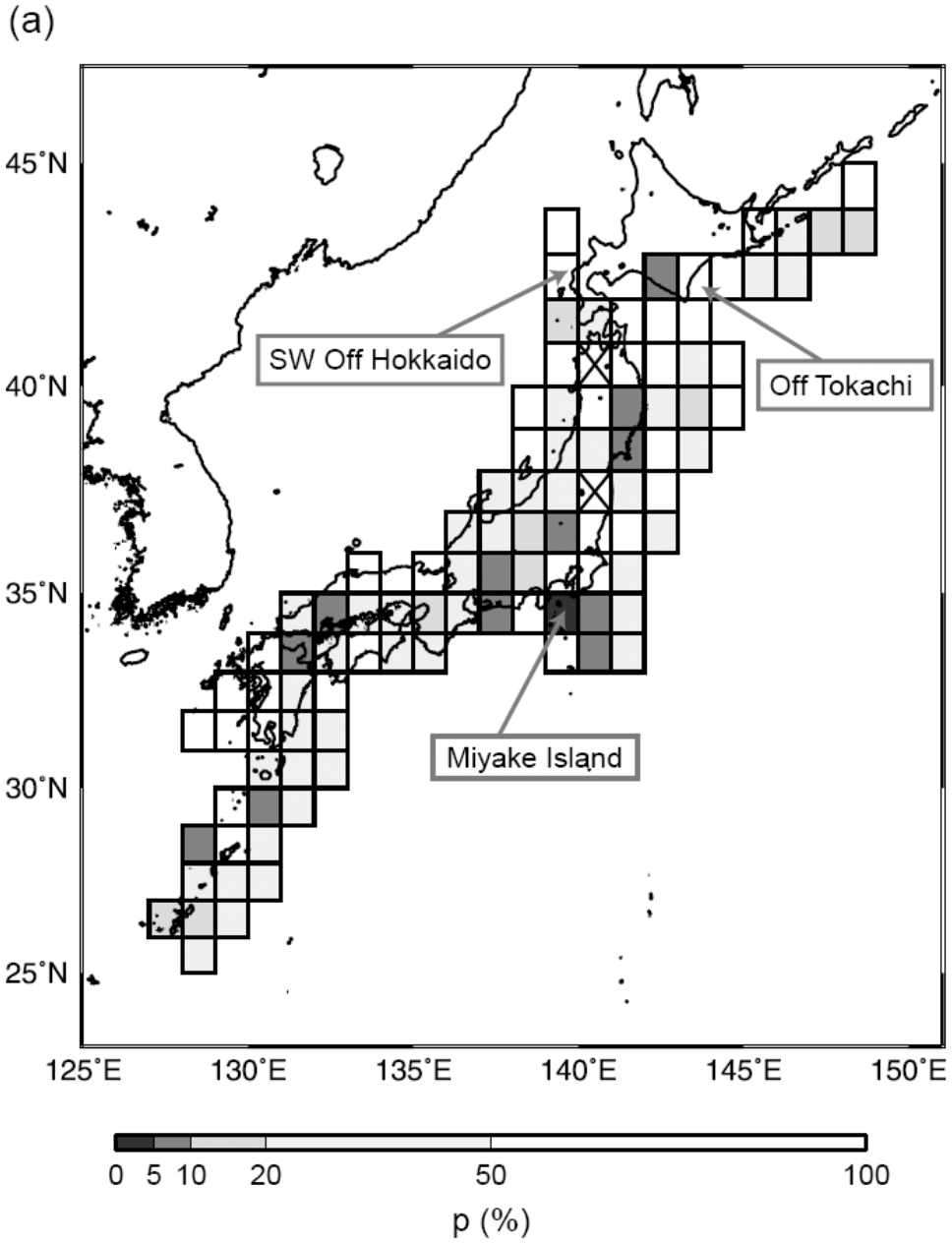
METHOD

- We investigate the correlation between the Earth tide and earthquake occurrence by statistically comparing the **azimuthal distribution** of a tidal stress component obtained for **the observed earthquake occurrence** with that **synthesized for random earthquake occurrence.**
- Tidal azimuth : horizontal projection of the maximum principal axis (maximum compression) of the tidal stress tensor.
- Tidal stress tensor : theoretically calculated for the Preliminary Reference Earth Model (Dziewonski and Anderson, 1981) following the method of Tanaka *et al. (2002b).*
- This calculation includes both the direct solid Earth tide and indirect term due to the ocean loading by using the **ocean tide model NAO.99b** (Matsumoto *et al., 2000; Takanezawa et al., 2001).*

Method of Statistical Test

- For each subregion, we obtain two frequency distributions of the azimuthal angles : the distribution for the observed earthquake data and that for the synthesized random data.
- We statistically compare these two distributions by usingthe χ^2 *test*.
- We assess the significance level p for rejection of the null hypothesis. A significant difference between the two distributions means that earthquakes do not occur randomly with the azimuth of the tidal compressional stress.
- The smaller p-value indicates a higher correlation between the Earth tide and earthquake occurrence.

Result

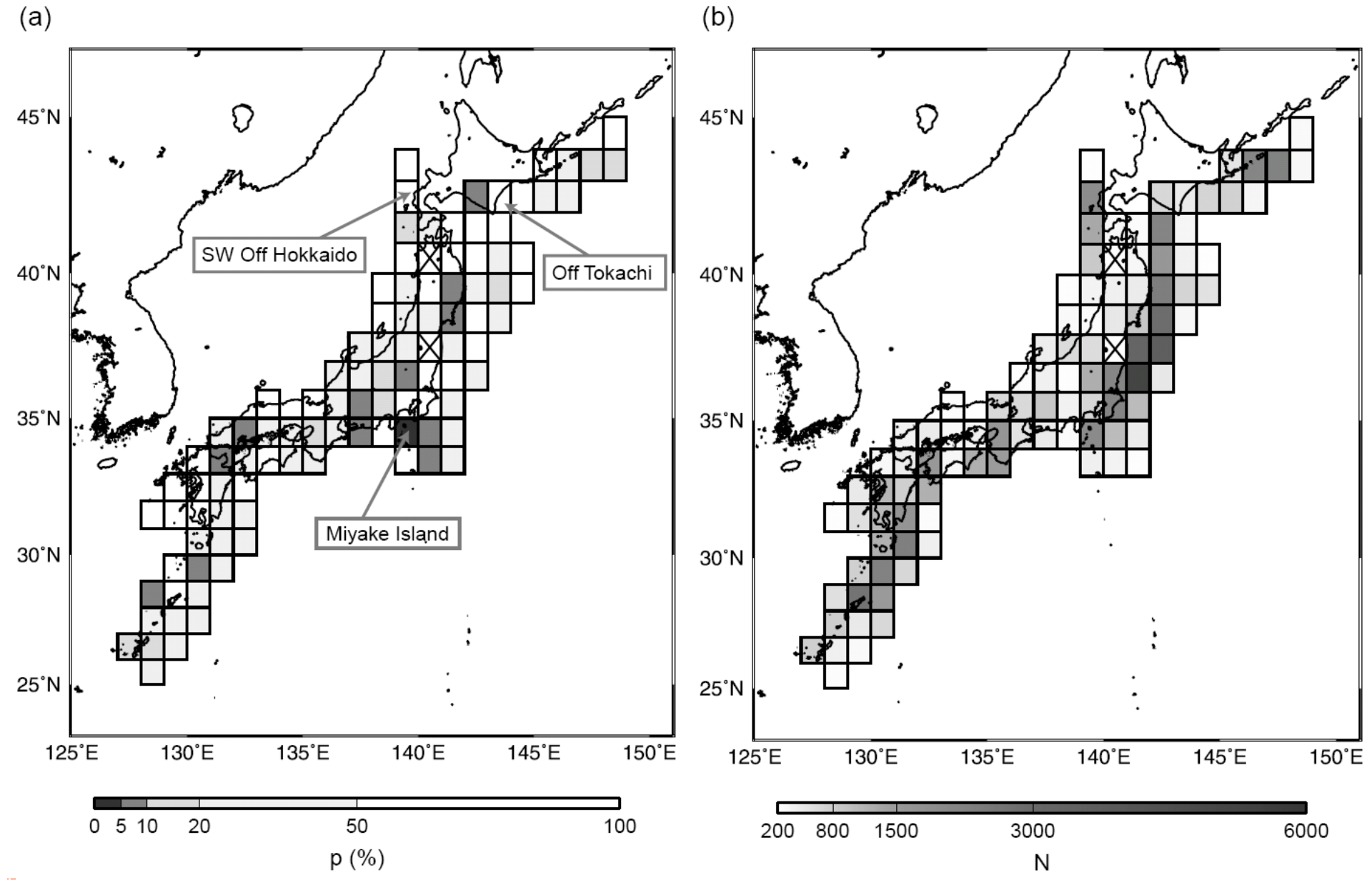


- Darker shades represent smaller p-values
- $p < 5\%$: 1

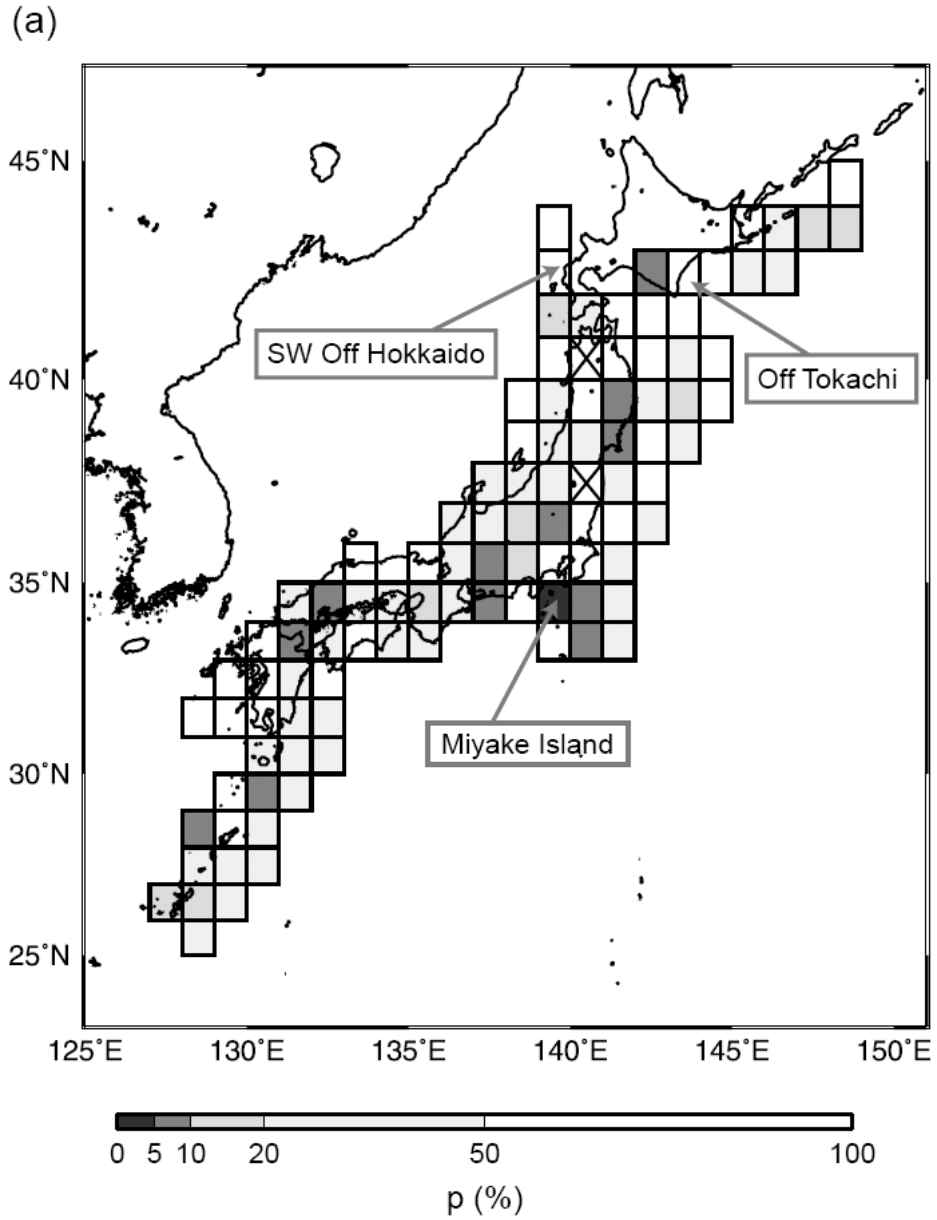
  $5\% \leq p < 10\%$: 12

Result

- A systematic correlation is not seen between the observed *p*-value and the number of the earthquakes.

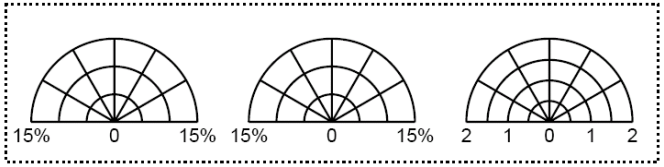


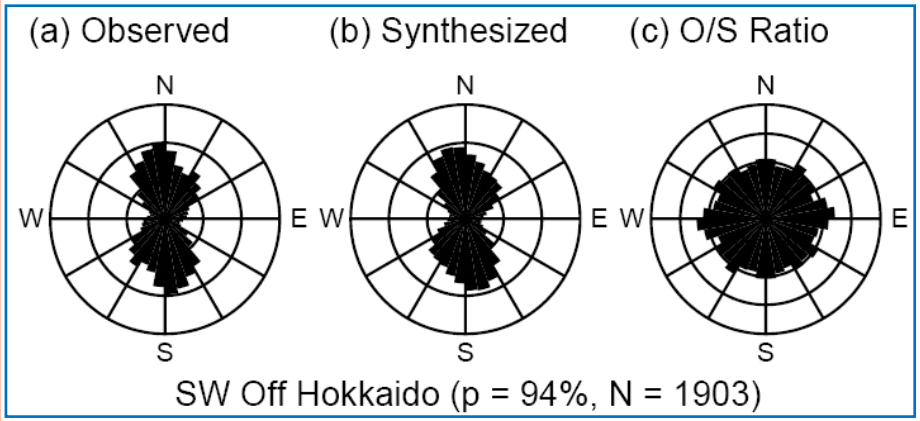
Result

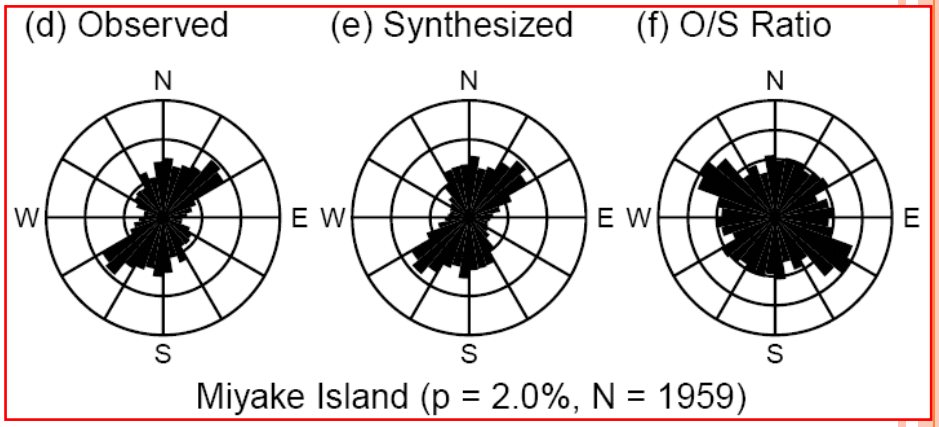


- The tidally-correlated subregions are associated with a variety of tectonic environments.
- the subduction zone : 7
- intraplate region with active faults : 4
- volcanic area: 2
- The smallest p-value of 2.0% is observed for the Miyake Island subregion as known for a typical volcanic area.
- Shift by half of grid size => same result

Result

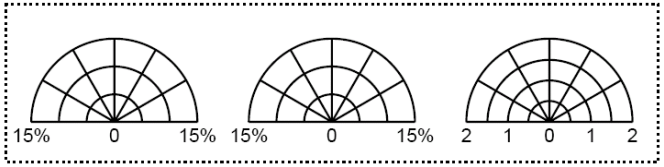


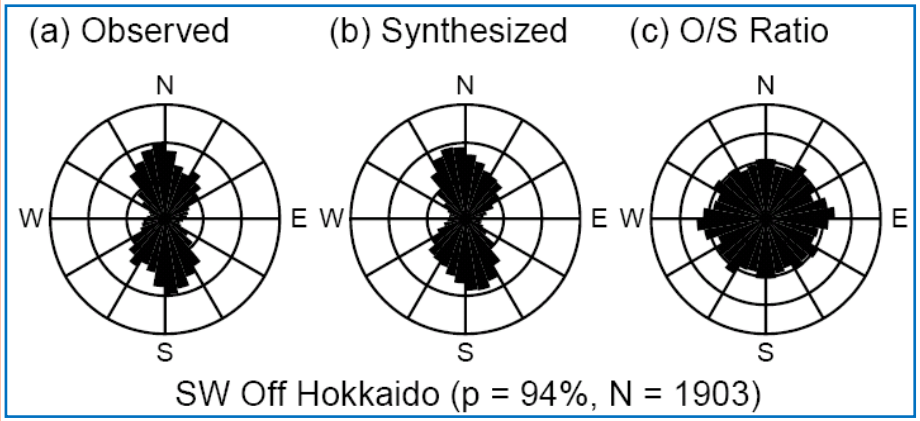


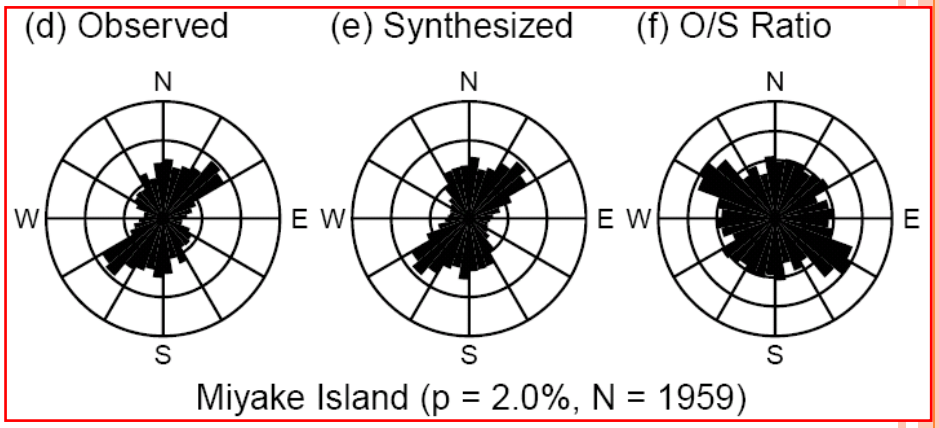


- Examples of the azimuthal distributions of the tidal compressional stress for the observed earthquake occurrence (a, d) compared with random occurrence (b, e).
- The azimuth of the tidal compressional stress does not distribute uniformly even for the synthesized random occurrence. Two reasons : orbit of the Moon and the Sun, and the azimuthal distribution of the ocean loading sources.

Result







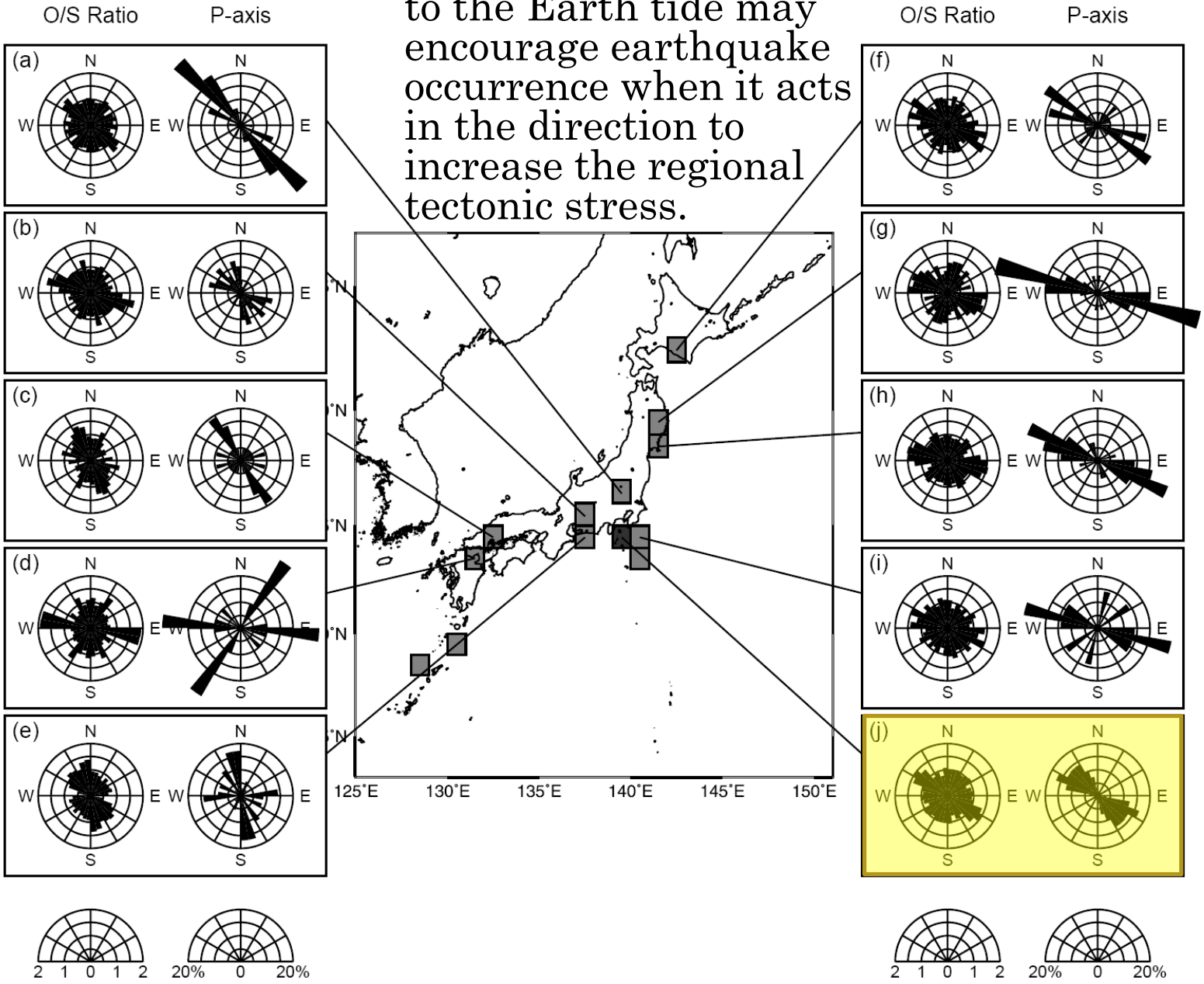
- In order to make visible the difference between the two distributions, we take the ratio (O/S ration) of the proportion for the observed and synthesized data for each azimuth bin of 10◦- width.
- O/S ratio ~ 1.0 in all directions : no correlation between the Earth tide and earthquake occurrence.
- A high value of the O/S ratio means that the corresponding azimuth is preferred by earthquake occurrence.

Result

- Tanaka et al. (2002b) shows that earthquakes tend to occur when the tidal stress adds to the tectonic stress. From this result, it is expected that the anomalous azimuth may be aligned with the tectonic stress field.
- Compared with the azimuthal distribution of O/S ratio and the frequency distribution of the P-axis direction of focal mechanisms obtained in the corresponding subregion by JMA.
- The comparison is made for the ten subregions with $p < 10\%$ for which focal mechanism solutions are available.

Result

- This suggests that a small stress change due to the Earth tide may encourage earthquake occurrence when it acts in the direction to increase the regional tectonic stress.

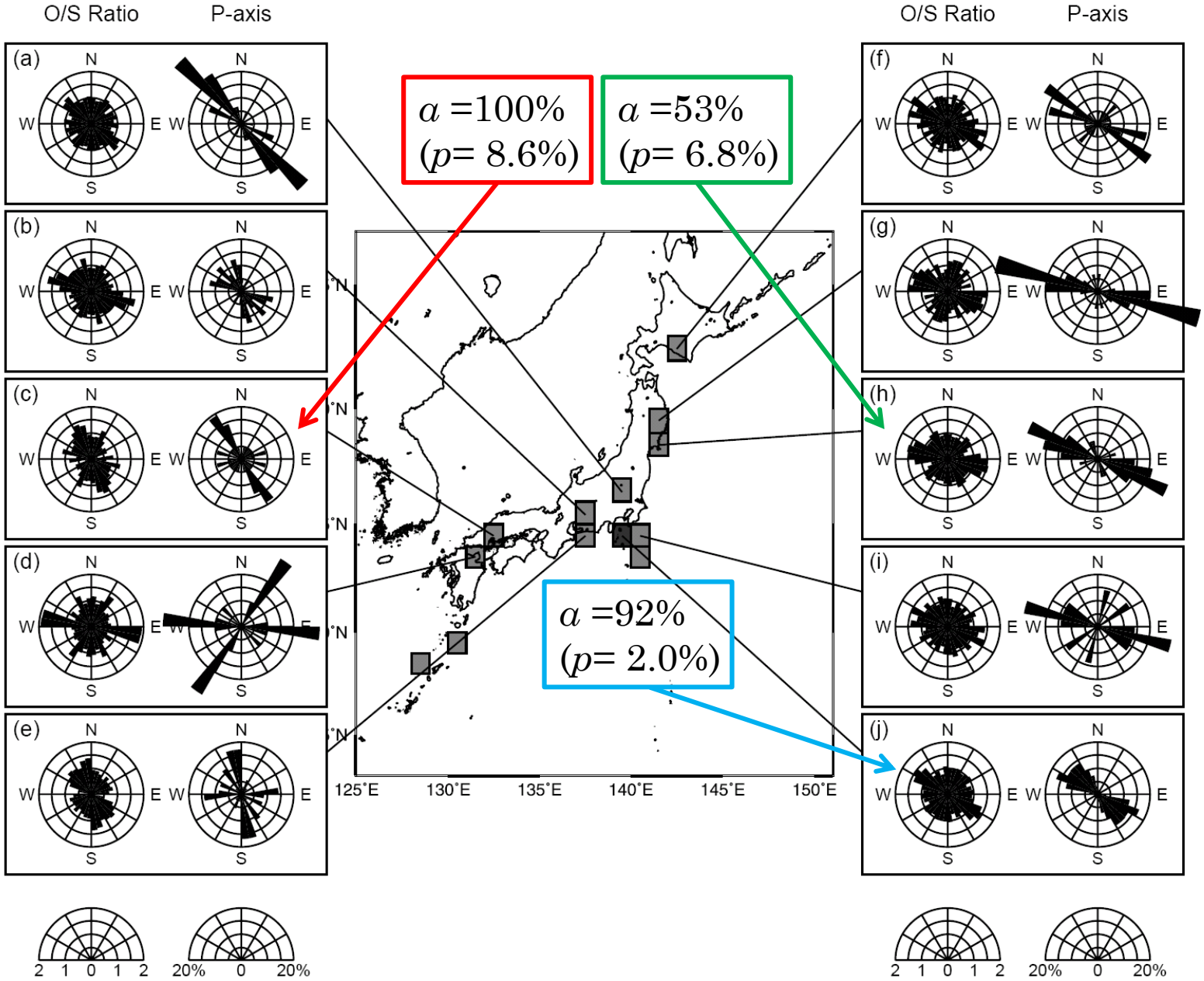


Result

- In order to statistically compare the azimuthal distribution of the O/S ratio with that of the P-axis direction, we perform the χ^2 *test*. In this test, we assess the significance level α to reject the null hypothesis that these two distributions are samples from the same population.

Result

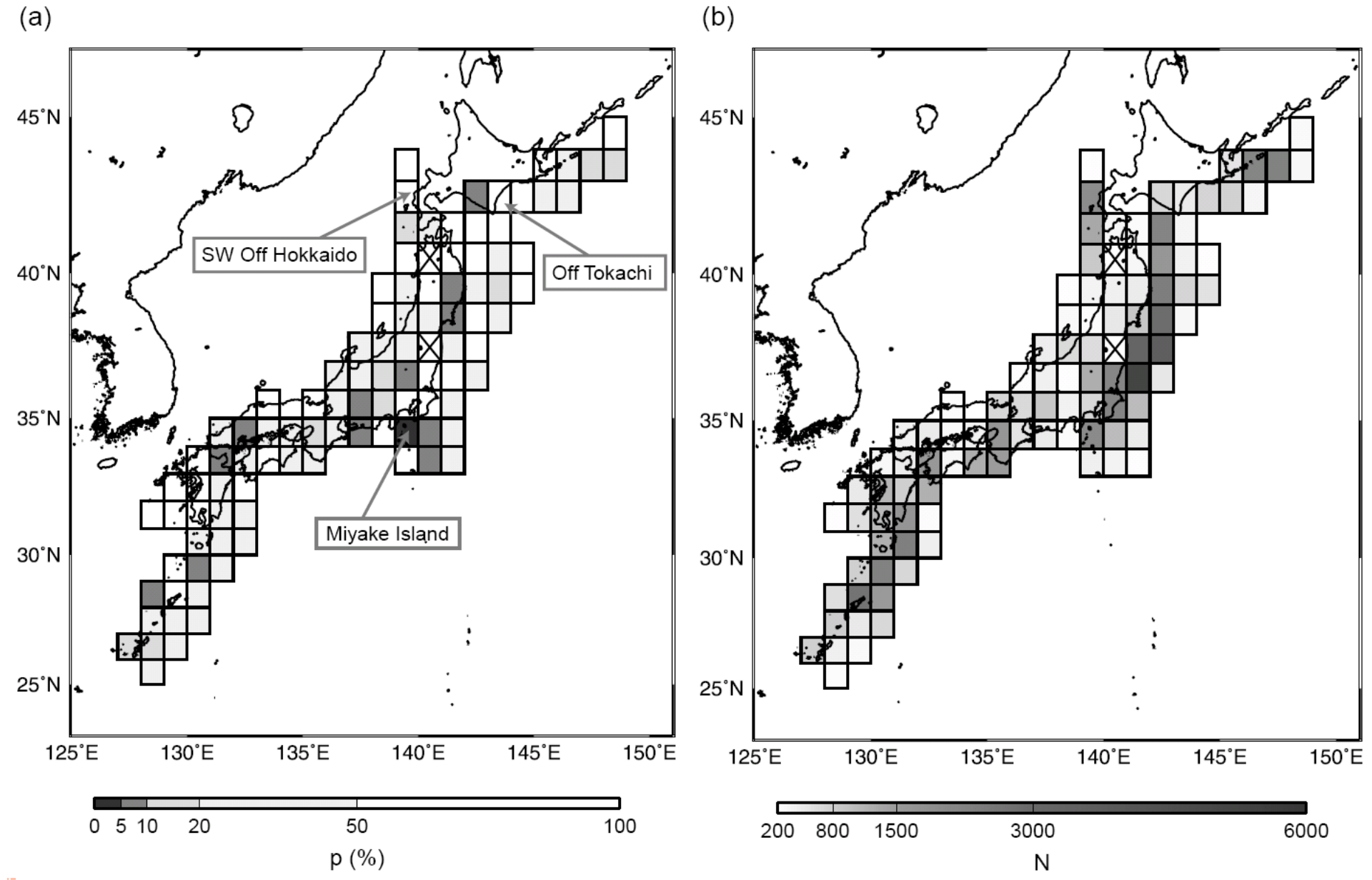
- we obtain $\alpha = 35 - 100\%$.



DISSCUSSION

- Why the tidal effect is evident in only 13% of the Japan archipelago ?
  - Recent studies have indicated that the tidal effect on earthquake occurrence may appear only when the stress state is approaching a critical level just before the occurrence of a large earthquake.

    (Yin et al., 1995, 2000, Tanaka et al.,2002a)
- In the light of these results, one interpretation of our results is that regions with a significant correlation may have a near-critical stress state.
- Some example : 1) in the Miyake Island subregion where the smallest *p*-value of 2.0% was observed, unusual seismic activity including five $M_{JMA} \geq 6.0$ earthquakes took place in June-August 2000. 2) in the Aki Nada subregion of $p = 8.6$ the *Geiyo* earthquake (M_{JMA} 6.7*)* occurred on 24 March 2001. …


(a)
45°N
40°N
35°N
30°N
25°N
125°E
130°E
135°E
140°E
145°E
150°E
SW Off Hokkaido
Off Tokachi
Miyake Island
0 5 10 20 50 100
p (%)
(b)
45°N
40°N
35°N
30°N
25°N
125°E
130°E
135°E
140°E
145°E
150°E
200 800 1500 3000 6000
N

Disscussion

- For the Miyake Island subregion, we perform the analysis dividing the earthquake data into two periods: before and after the seismic activity in June-August 2000. pre-seismic period : a smaller *p-value of 1.2%* post-seismic period : a larger value of 17% This is in good harmony with the result of Tanaka *et al. (2002a)*.
- We note that the Off Tokachi earthquake on 26 September 2003 (M_{JMA} 8.0) occurred in an insignificant subregion but close to the significant subregion of p = 8.4%. We also note that small *p*-values were observed for two subregions where the possibility of large earthquakes has been argued.
- Tanaka *et al.* (2004) : our observation provides new evidence that even such a small stress change can trigger an earthquake.

Disscussion

- Why can we not more readily see a seismic response to the ubiquitous and predictable tides?
  - Magnitude and frequency.
- Next we have to check:
  1. the tidal stress is unusually strong in these subject or not.
  2. faults might need to be uniformly oriented for tidal triggering to be detected.
  3. The 13 regions could have unusually low fault friction.
- Examining the results in California and Taiwan.
- Testing case with unusually large tidal stress changes due to ocean loading.

Conclusion

- We examined the direction of the maximum principal axis of the tidal stress tensor at the origin times and the hypocenters of 89,504 shallow earthquakes occurring in the 100 subregions in Japan.
- Significant difference between the two distributions ($p < 10\%$) was found for 13 subregions. => O/S ratio
- High value of this ratio, which means that the corresponding azimuth is preferred by earthquake occurrence, was found to concentrate in and around the dominant direction of the P-axes of focal mechanisms obtained in the corresponding subregion.
- Studies on tidal triggering of earthquakes may provide a new clue to reveal the physical mechanism of rupture initiation.

Thank you for your attention !!