

# Supporting Information for “Identifying the recurrence patterns of non-volcanic tremors using a 2D hidden Markov model with extra zeros”

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## Introduction

This file contains 1) results from East Kii region, 2) the migration pattern of segments obtained through the Viterbi path together with the probabilities that the system is in each state at each time point for the entire data sets from the Kii and Shikoku regions from 2001 to 2012.

### Text S1: East Kii region

No tremors are seen in the upper states 12, 13 and 14 of the Kii region for approximately the first year of data provided. This was due to the fact that not many stations were installed in that region in 2001. Also, tremors to the southwest tip of the Kii region seem to form an independent subsystem and have largely disappeared since 2010. We therefore removed the data in subsystem (K1) (segments 1–3) and only analysed data from 2002 to 2012.

The best model according to the BIC is the model with 15 states (Table S1). Comparing Figure S1 with Figure 3 in the main manuscript we can see that most of the classifications do not change except that segments 4–6 from the 17-state model are now reclustered into four segments. Segment 5 in the 17-state model is now separated into two segments, 1 and 3, with active transitions between them. Segments 4 and 6 are now reclassified into segments 2 and 4. Segment 2 features weak tremors. Figure S1 also shows segments 15 and 17 from the 17-state model as segments 12 and 15 in the 15 state model respectively.

The classification of subsystems is similar to the results from the entire data set. We have three subsystems (K2), (K3) and (K4) comprising segments 1–3, segments 4—10, and segments 9–13 respectively as shown in Figure S1. The latter two subsystems (K3) and (K4) often behave as one large system, but not always. Segments 9 and 10 often act as the intermediate states when there is migration through this combined larger system.

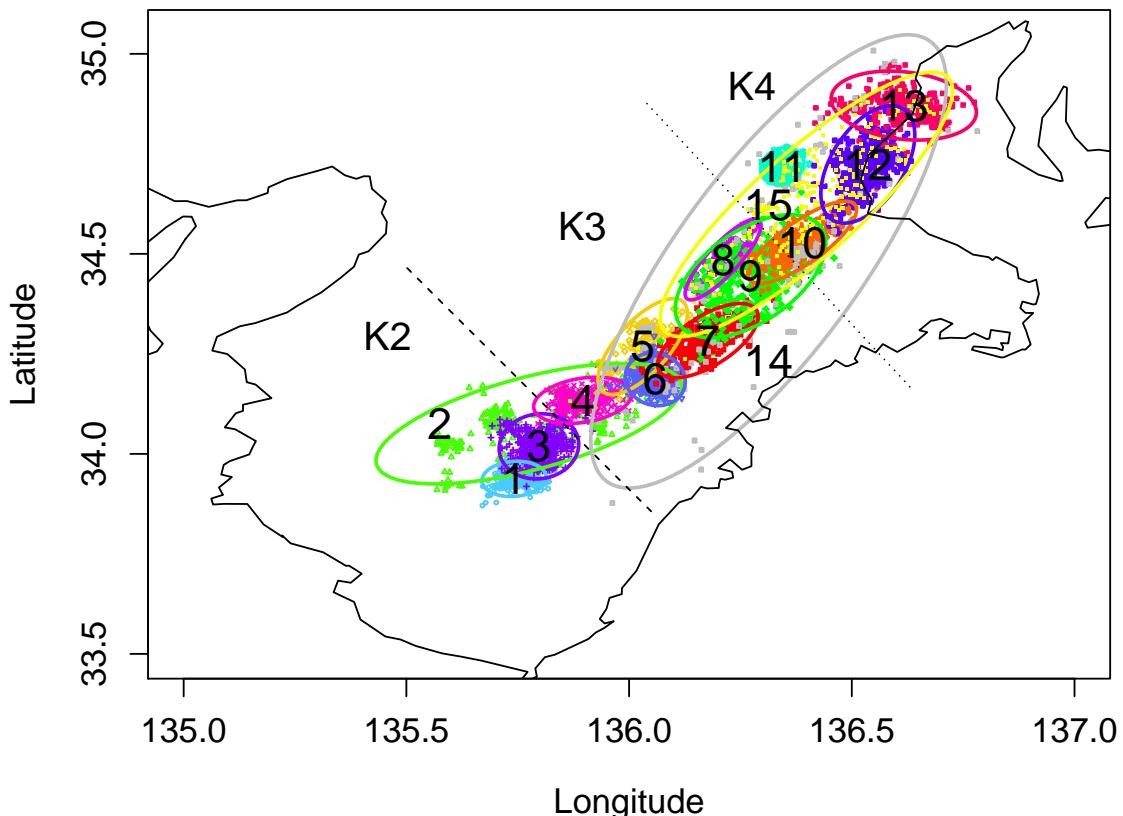
Southwest migration from segment 13 through to segment 4 is more likely than northeast migration from segment 4 through to segment 13. State 14 represents the background state with low probability of tremor occurrence. The pattern revealed in Figure S4 is similar to that in Figure 7 in the main manuscript. The estimated parameters for the segments that correspond to each other in Table S1 and Table 1 in the main manuscript are also similar to each other.

### **Text S2: Viterbi path**

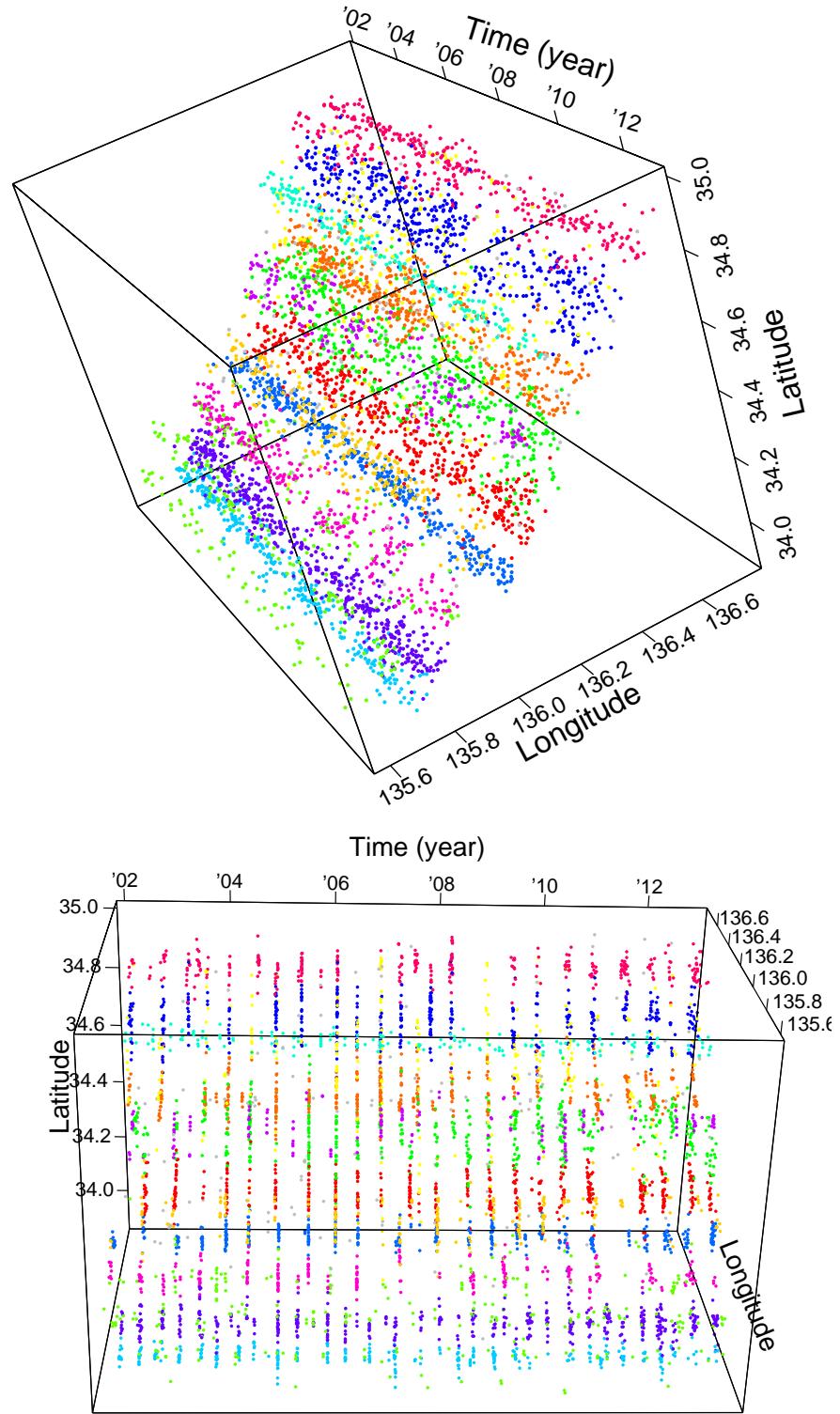
The spatial and temporal migration between segments is demonstrated by the Viterbi path with latitude and longitude time series. Figures S5 and S6 show the pattern of the full record in the Kii and Shikoku regions.

**Table S1.** Parameter estimates from the 15-state HMM fitted to the east Kii region. S: state;  $\hat{p}_i$ : the estimated probability of observing a tremor event when the system is in state  $i$ ;  $\hat{\pi}_i$ : the estimated stationary probabilities of the hidden Markov chain;  $\hat{T}_S$ : the average empirical sojourn times (in hours).

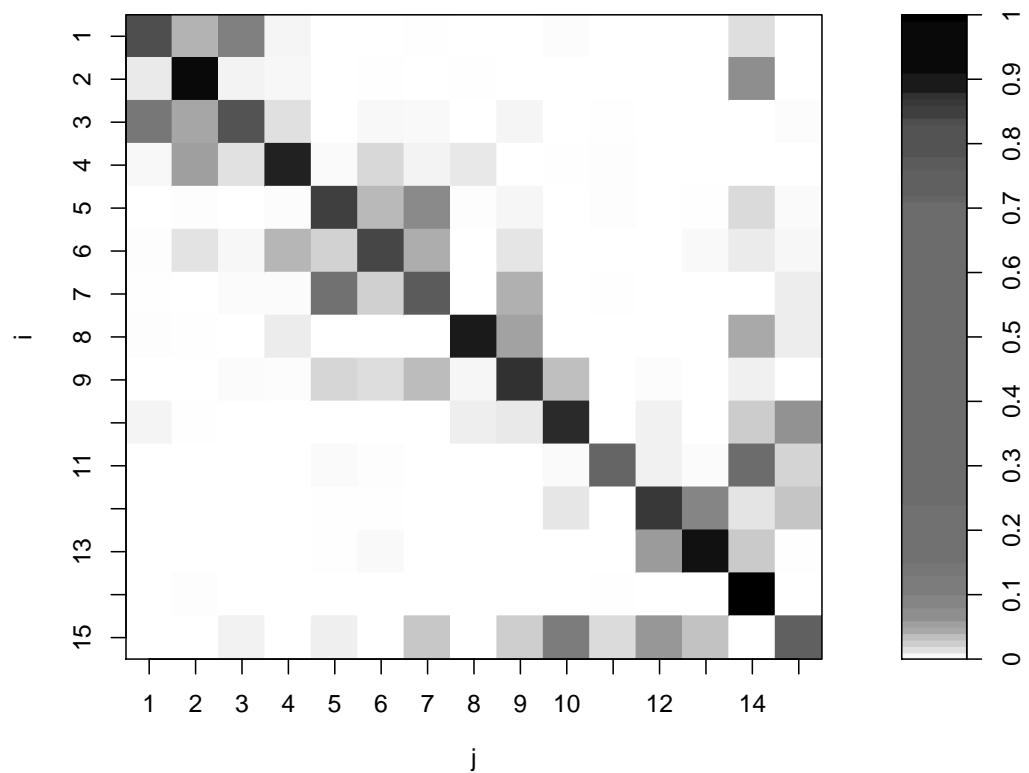
S	1	2	3	4	5	6	7	8	9	10
$\hat{p}_i$	0.325	0.072	0.741	0.452	0.226	0.666	0.725	0.422	0.707	0.534
$\hat{\pi}_i$	0.010	0.040	0.007	0.006	0.010	0.006	0.007	0.004	0.007	0.008
$\hat{T}_S$	7.4	11.3	5.1	10.6	7.6	7.0	4.9	9.4	9.5	10.3
S	11	12	13	14	15					
$\hat{p}_i$	0.384	0.539	0.250	0.001	0.811					
$\hat{\pi}_i$	0.005	0.008	0.014	0.864	0.004					
$\hat{T}_S$	2.9	9.6	15.2	273.9	3.8					



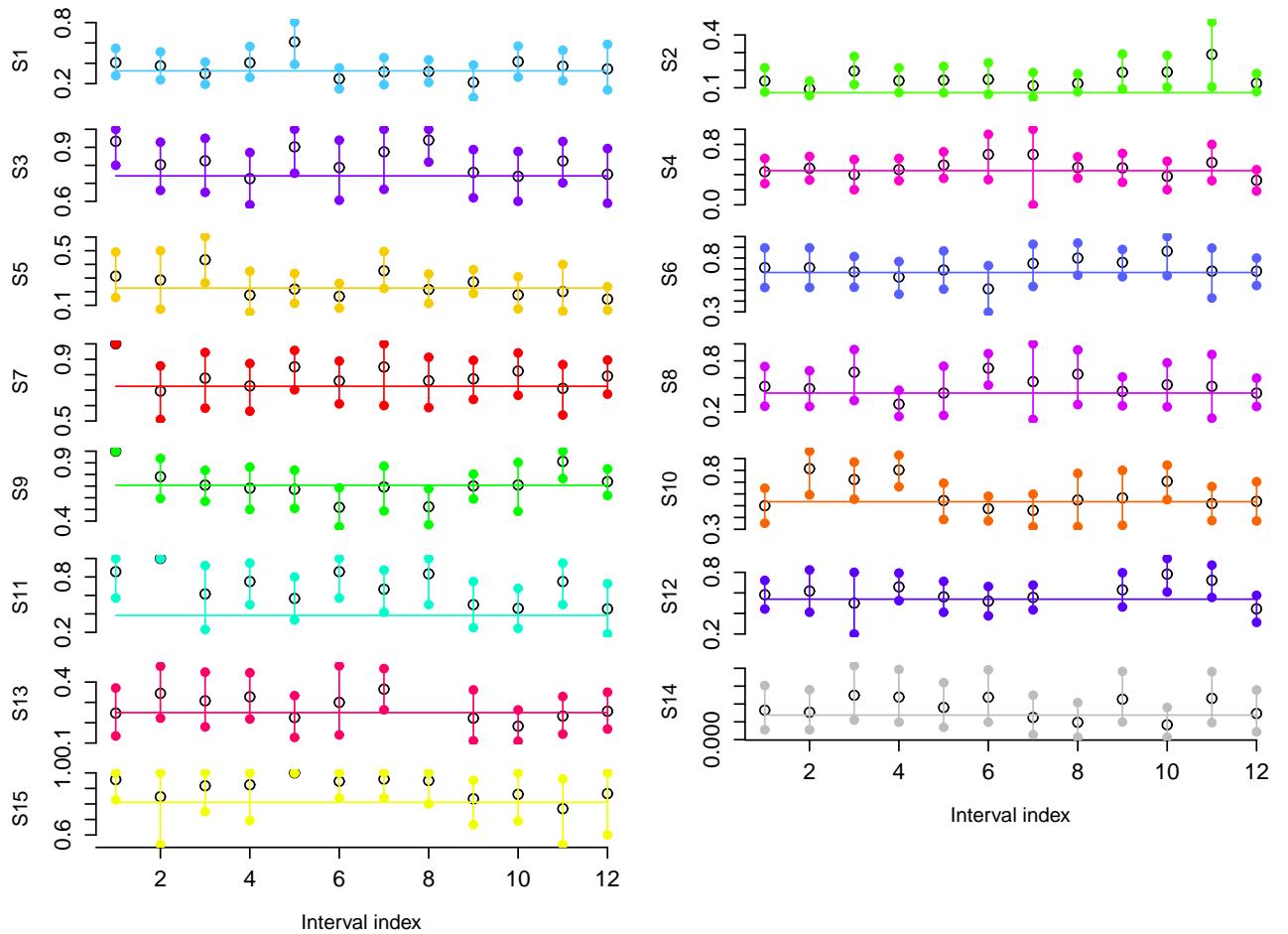
**Figure S1.** Classification of distinct spatial segments of tremor events in the east Kii region obtained from the 15-state 2D HMM. The points represent the hourly centroid locations of tremors for times when tremor occurred. State 14 is in gray and State 15 is in yellow.



**Figure S2.** Spatiotemporal classification of distinct spatial segments of tremor events in the east Kii region obtained from the 15-state 2D HMM.

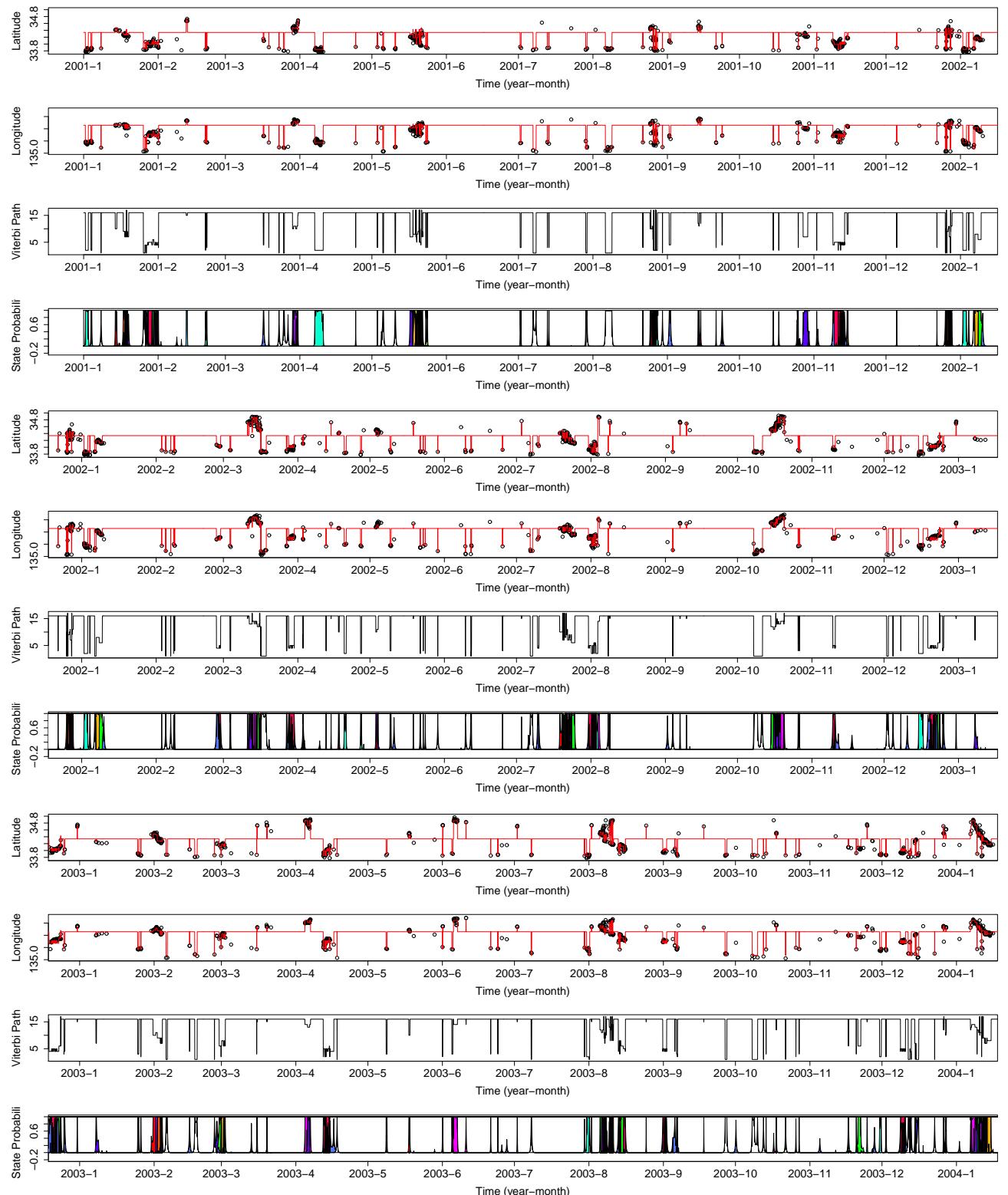


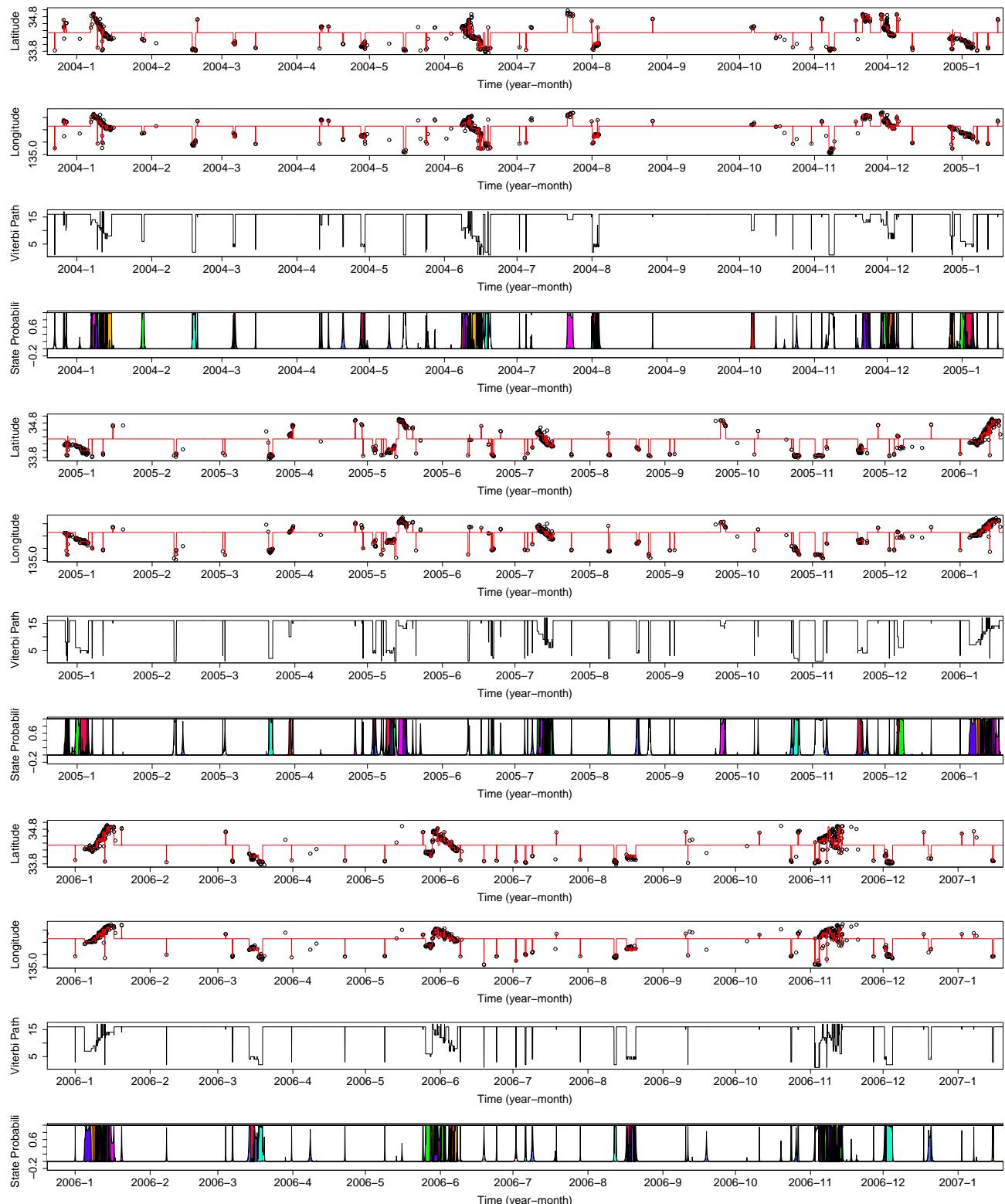
**Figure S3.** The transition probabilities  $\Pr\{S_t = j \mid S_{t-1} = i\} = \gamma_{ij}$  estimated from the 15-state 2D HMM for the east Kii region.

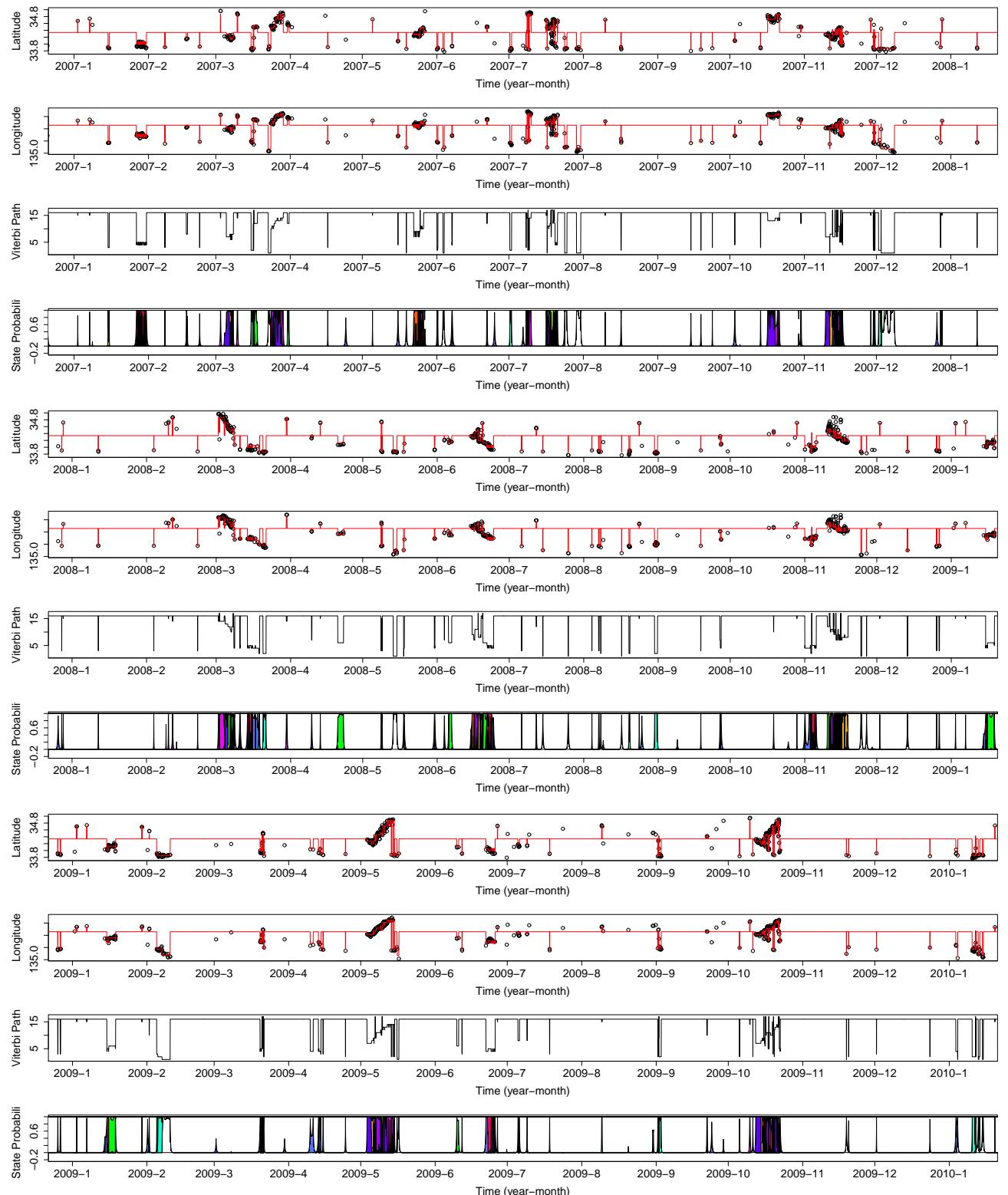


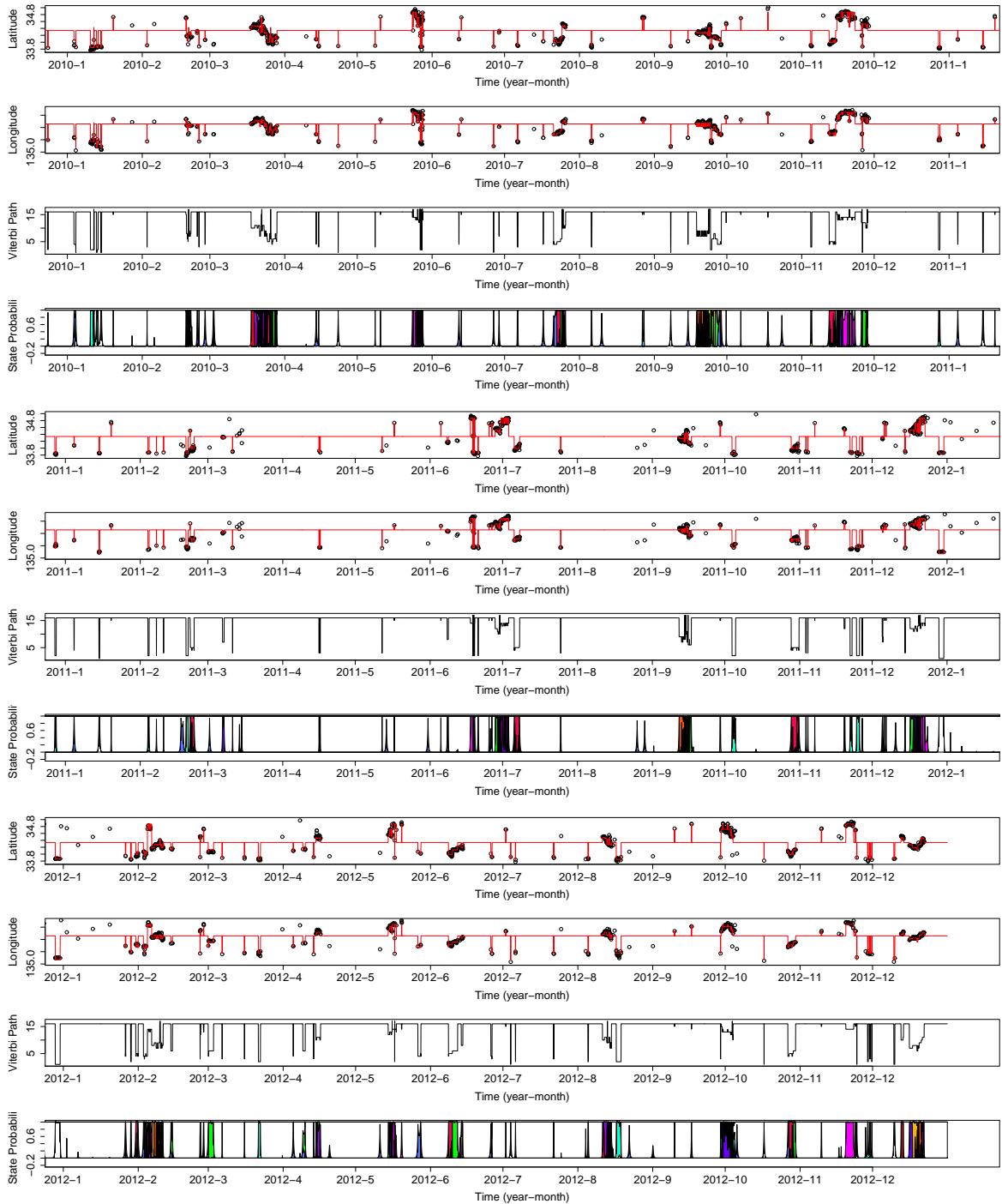
**Figure S4.** The proportion of tremors in each state over 12 intervals for the east Kii region.

Each interval is about one year. Each circle indicates the proportion of tremors in each state in that interval obtained from the Viterbi path. The vertical bar shows the 99% confidence interval of this proportion. The horizontal line represents the estimated  $p_i$  from the HMM.



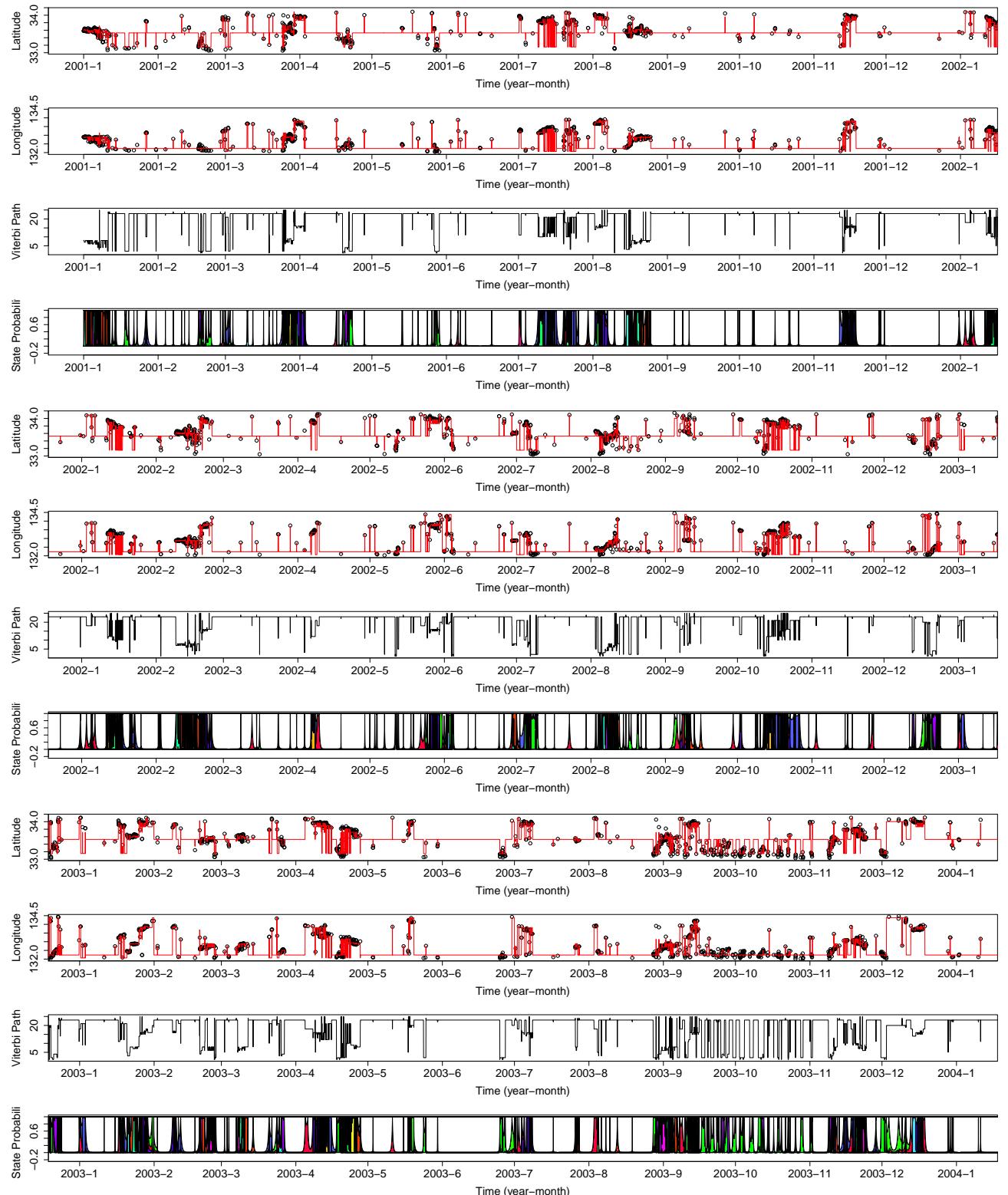


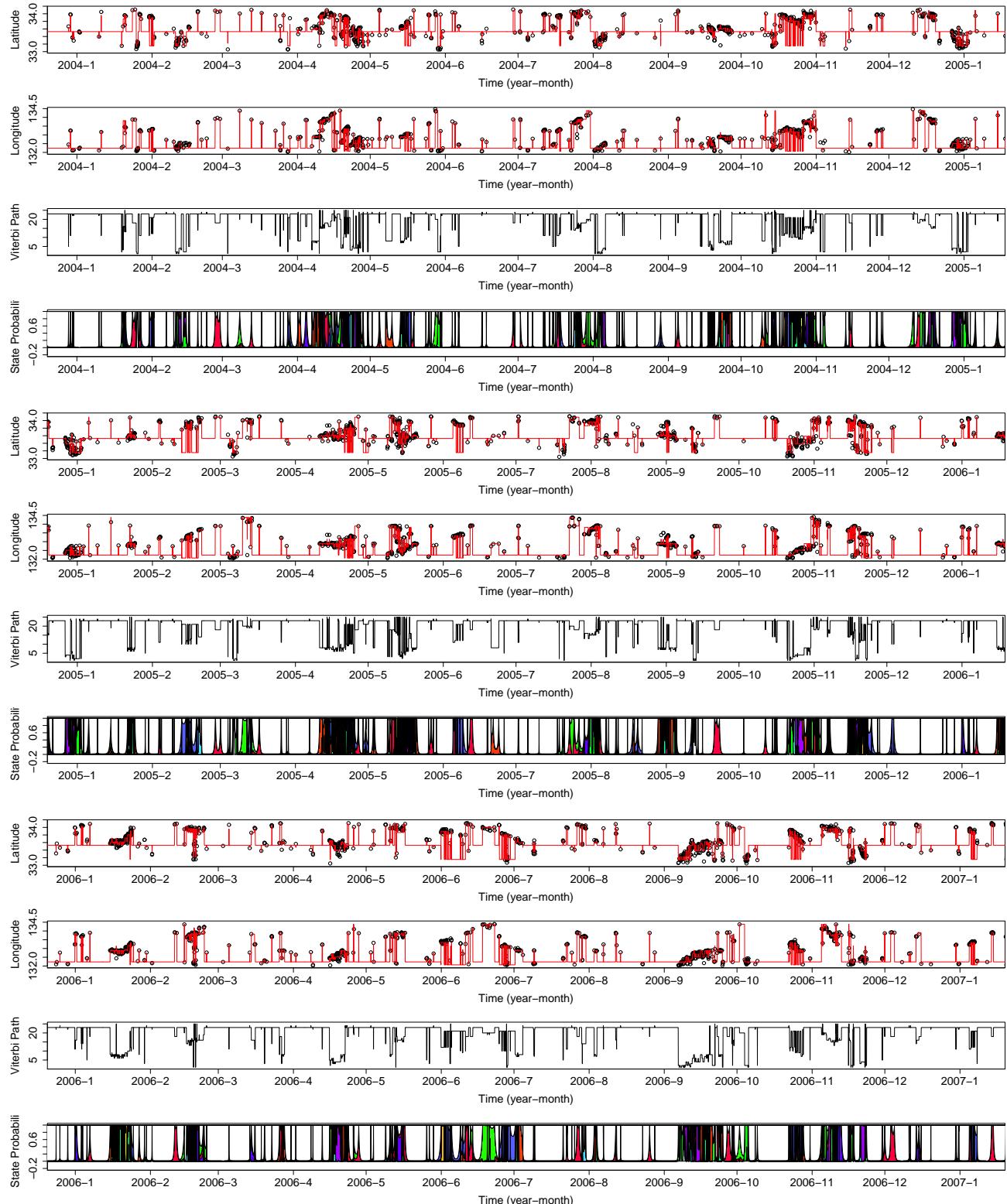


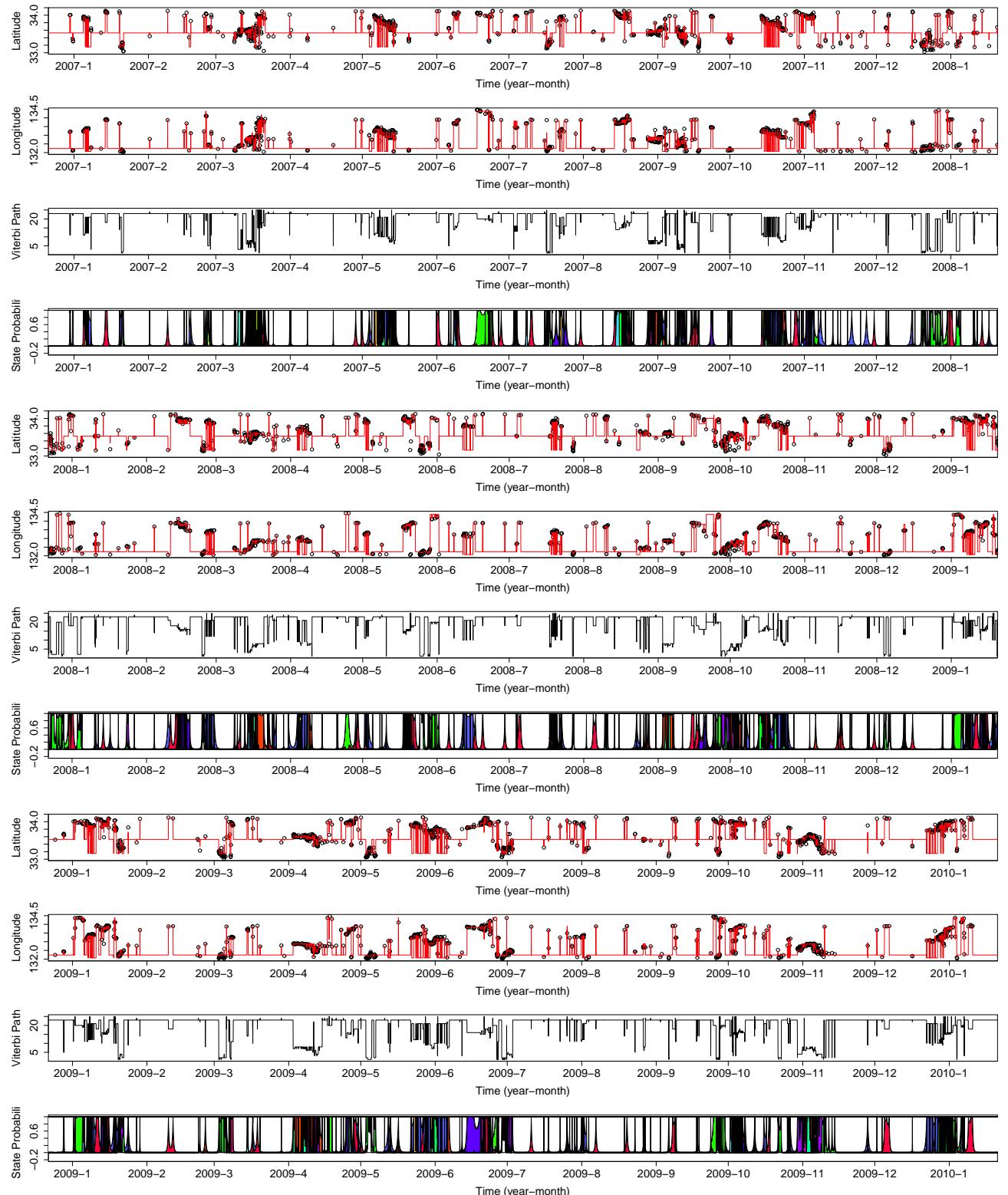


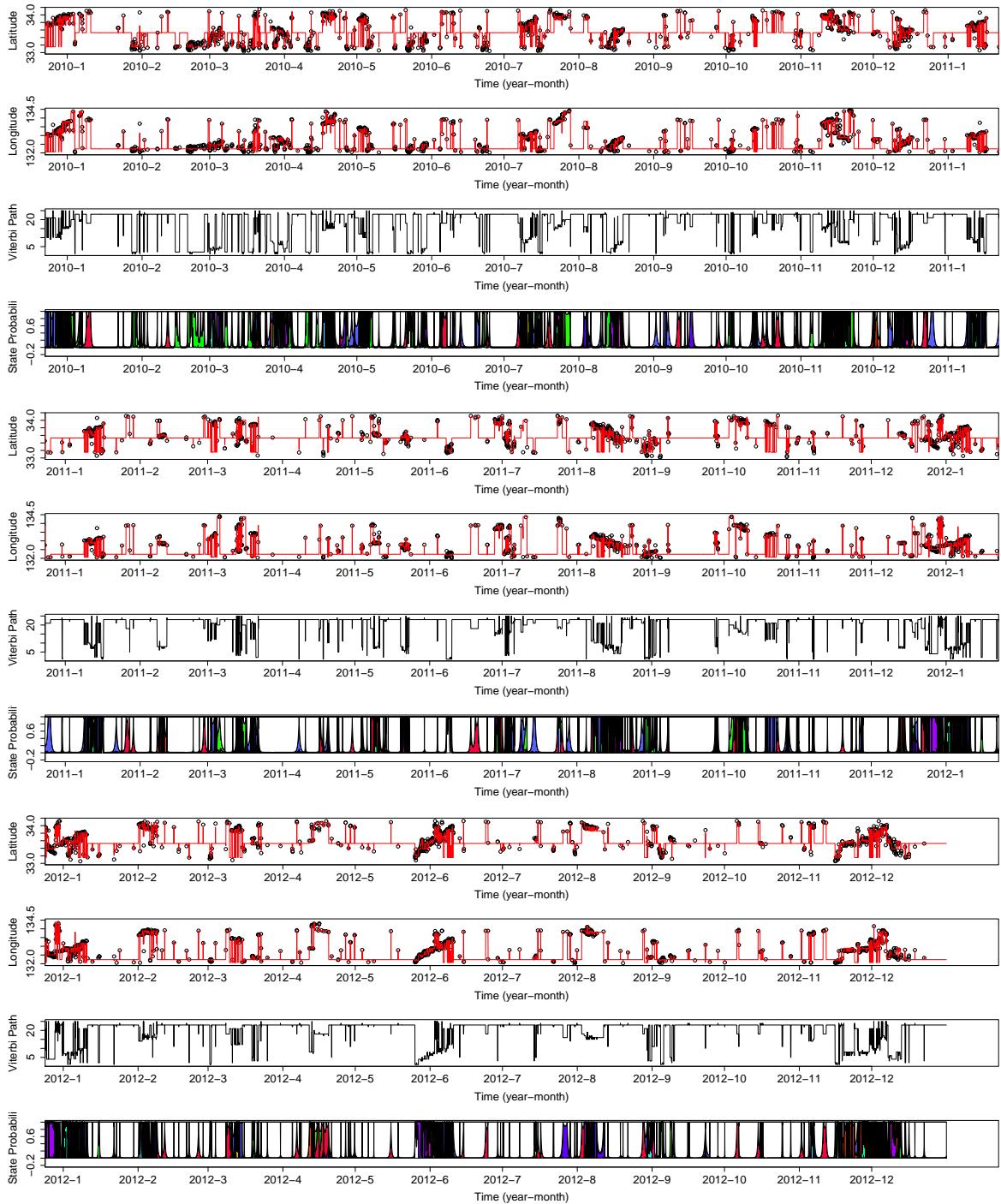
**Figure S5.** Spatio-temporal migration pattern of tremors in the Kii region (17-state 2D HMM).

Top two panels: Observed latitudes and longitudes with the center  $\hat{\mu}_i$  of each state overlaid as the red lines; third panel: tracked most likely state sequence of the HMM; bottom panel: the estimated probability of the data being in each state, with blank representing the probability of being in state 16 (the null state).









**Figure S6.** Spatio-temporal migration pattern of tremors in the Shikoku region (25-state 2D HMM). Top two panels: Observed latitudes and longitudes with the center  $\hat{\mu}_i$  of each state overlaid as the red lines; third panel: tracked most likely state sequence of the HMM; bottom panel: the estimated probability of the data being in each state, with blank representing the probability of being in state 23 (the null state).