$C(r)$ of $\alpha(\mathbf{r})$ can be introduced

$$C(r) = \left\langle \cos[\alpha(\mathbf{r} + \mathbf{r}_0) - \alpha(\mathbf{r}_0)] \right\rangle_{\mathbf{r}_0}, \tag{2}$$

where $r = |\mathbf{r}|$ denotes the distance between any two points. By analogy with the two-dimensional XY model (Käser *et al.*, 2007), it is conjectured that $C(r)$ is expressed as $\exp(-r/\xi)$ and that the correlation length ξ corresponds to the average distance between the nearest defects. As observed in Fig. 3(a), ξ is sufficiently larger than λ.

Each point in the image of a snapshot of spatiotemporal intermittency is classified as either turbulent or ordered. Figure 3(b) is obtained from Fig. 2(b) by this classification. In this view, spatiotemporal intermittency is similar to an Ising spin system or a percolation system. In the percolation model, the two-point correlation function is defined as the probability that two specified points are included in the same cluster of a state. If each cite is in the state with probability p,

$$C(r) = p^r = \exp\left(-\frac{r}{\xi}\right), \tag{3}$$

where $\xi = -1/\ln p$ corresponds to the average diameter of the cluster (Stauffer and Aharony, 1994). If an analogy between the percolation model and spatiotemporal intermittency is assumed, p corresponds to the areal fraction of the turbulent state, and ξ corresponds to the average diameter of the turbulent cluster. Also in this case, ξ is sufficiently larger than λ.

In soft-mode turbulence, with the local convective roll assuming any direction, a snapshot $u(\mathbf{r})$ is expressed as

$$u(\mathbf{r}) = R_0 \exp\big(i\mathbf{q}(\mathbf{r}) \cdot \mathbf{r}\big) + \text{c.c.}, \tag{4}$$

where R_0 is constant. The wavevector $\mathbf{q}(\mathbf{r})$ can be described only by the azimuthal angle ψ, namely,

$$\mathbf{q}(\mathbf{r}) = (q \cos\psi(\mathbf{r}), q \sin\psi(\mathbf{r})), \tag{5}$$

where $q = |\mathbf{q}(\mathbf{r})| = 2\pi/\lambda$ is constant. Figure 3(c) is a realization of $\psi(\mathbf{r})$ obtained from Fig. 2(c). This image shows that the spatial pattern consists of patches over which the direction of the local convective roll is uniform. The two-point correlation function for $\psi(r)$ decays as $\exp(-r/\xi)$ (Anugraha *et al.*, 2008) where the correlation length ξ corresponds to the average diameter of patches.

The property common to the three types of spatiotemporal chaos is that the correlation length ξ of disorder is sufficiently larger than the size λ corresponding to local order. This can be a universal criterion for spatiotemporal chaos in convective systems.

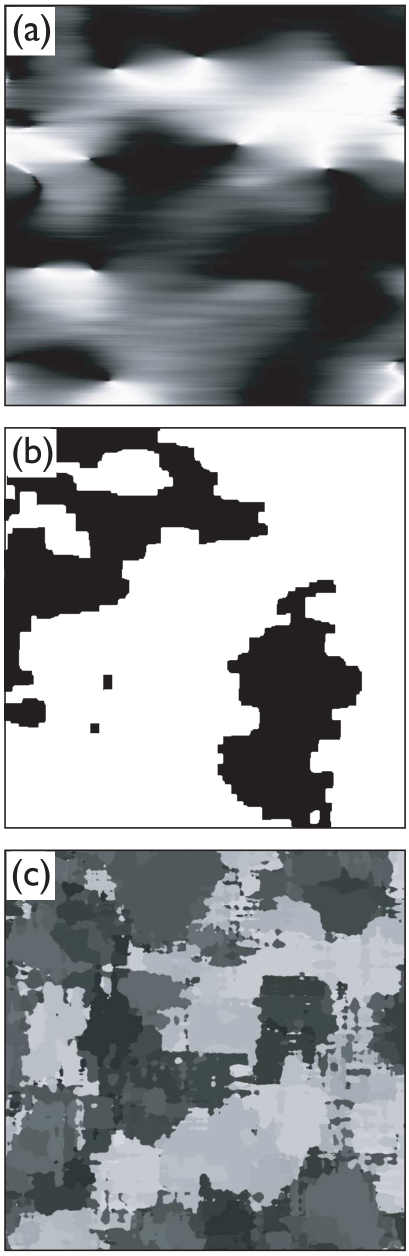

Fig. 3. Reduction patterns for the three types of spatiotemporal chaos. Each image corresponds to Fig. 2. (a) Gray scale indicates $\sin\alpha$. White and black correspond to $\sin\alpha = 1$ and -1, respectively. (b) White and black indicate ordered and turbulent states, respectively. (c) Gray-scale plot of ψ. White and black correspond to $\psi = \pi/2$ and $-\pi/2$, respectively.

5. Discussion

By adopting this criterion, spatiotemporal chaos can be distinguished from developed turbulence where ξ is much smaller than λ. Indeed, because convective rolls are broken in developed turbulence, we should express it as $\xi \ll d$.

In a system where chaos can be observed, $\Gamma \sim \mathcal{O}(1)$ implies $L \sim \lambda$, because $\lambda \sim d$. The fact that ξ is sufficiently larger than λ means that L is sufficiently smaller than ξ. Because ξ corresponds to the size of coherent motion, global coherence is kept in the system with L sufficiently smaller than ξ.

The order of convective structures remains in the scale range between λ and ξ in soft-mode turbulence and defect turbulence. This means order and disorder coexist. Recently the form of the temporal correlation function was found to change with the time range (Narumi *et al.*, 2013). It is thought that this "dual structure" reflects this coexistence.

The coexistence is explicit in spatiotemporal intermittency. The spatial correlation functions for defect turbulence and spatiotemporal intermittency have not been