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Quantitative analysis of cloud self-organization using Shannon’s information entropy: Results from radiative convective equilibrium experiments

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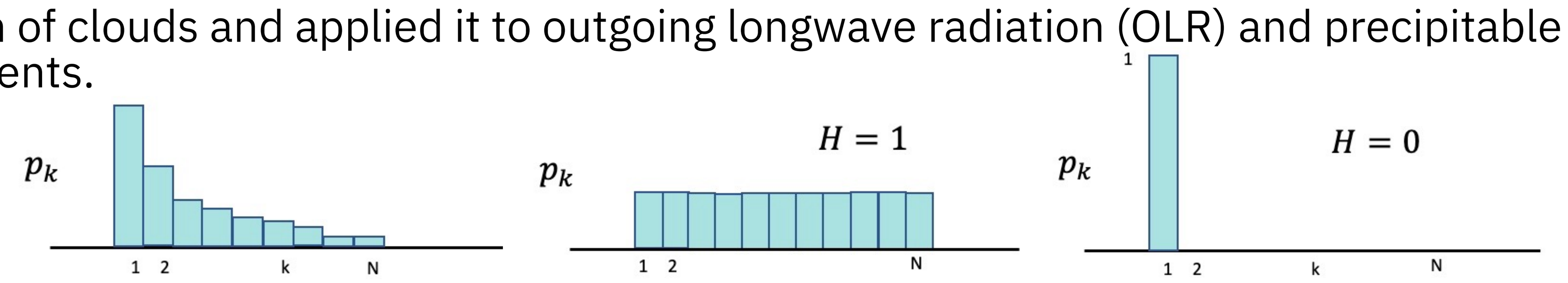
Introduction

Spatio-temporal variations in cloud cover have a significant impact on precipitation distribution and surface temperature. An index for cloud morphology related to self-organization that can be applied to a variety of physical quantities is beneficial.

We used information entropy as a measure to quantify the degree of self-organization of clouds and applied it to outgoing longwave radiation (OLR) and precipitable water (PW) data in three-dimensional radiative convective equilibrium (RCE) experiments.

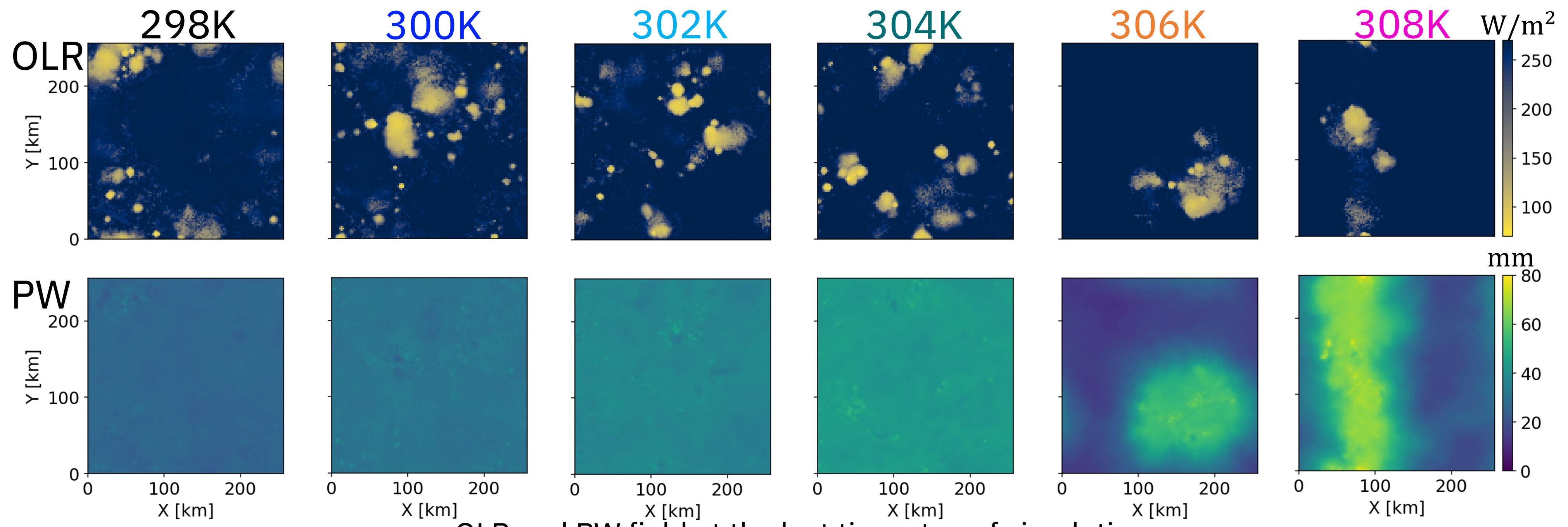
Normalized information entropy: $$H = -\frac{1}{\log N}\sum_{k=1}^{N} p_k \log p_k \quad \left(\sum_{k=1}^{N} p_k = 1\right)$$



Data and Methods

80-day RCE simulations with six fixed SSTs

	Settings
Horizontal grid spacing	2 km
Vertical grid spacing	Increasing from 100 m (z < 1 km) to 500 m (z > 10 km)
Domain size	X:256 km, Y:256 km, Z:21 km (bi-periodic)
Cumulus scheme	Not used
Cloud microphysics scheme	6-class single-moment bulk model (Tomita, 2008)
Radiation scheme	MSTRNX k-distribution-based broad-band radiation transfer model (Sekiguchi and Nakajima, 2008)



OLR and PW field at the last time step of simulations

Two methods for calculating information entropy were compared: a method using EOF, following a previous study (Li et al., 2018, applied to satellite observation data), and a method using two-dimensional Fourier transform.

1. PDF based on contribution rate of EOF decomposition

$u(\mathbf{r},t) = \sum_{k=1}^{N} \alpha_k \psi_k(t)\phi_k(\mathbf{r})$ (α_k: eigenvalue of the kth mode)

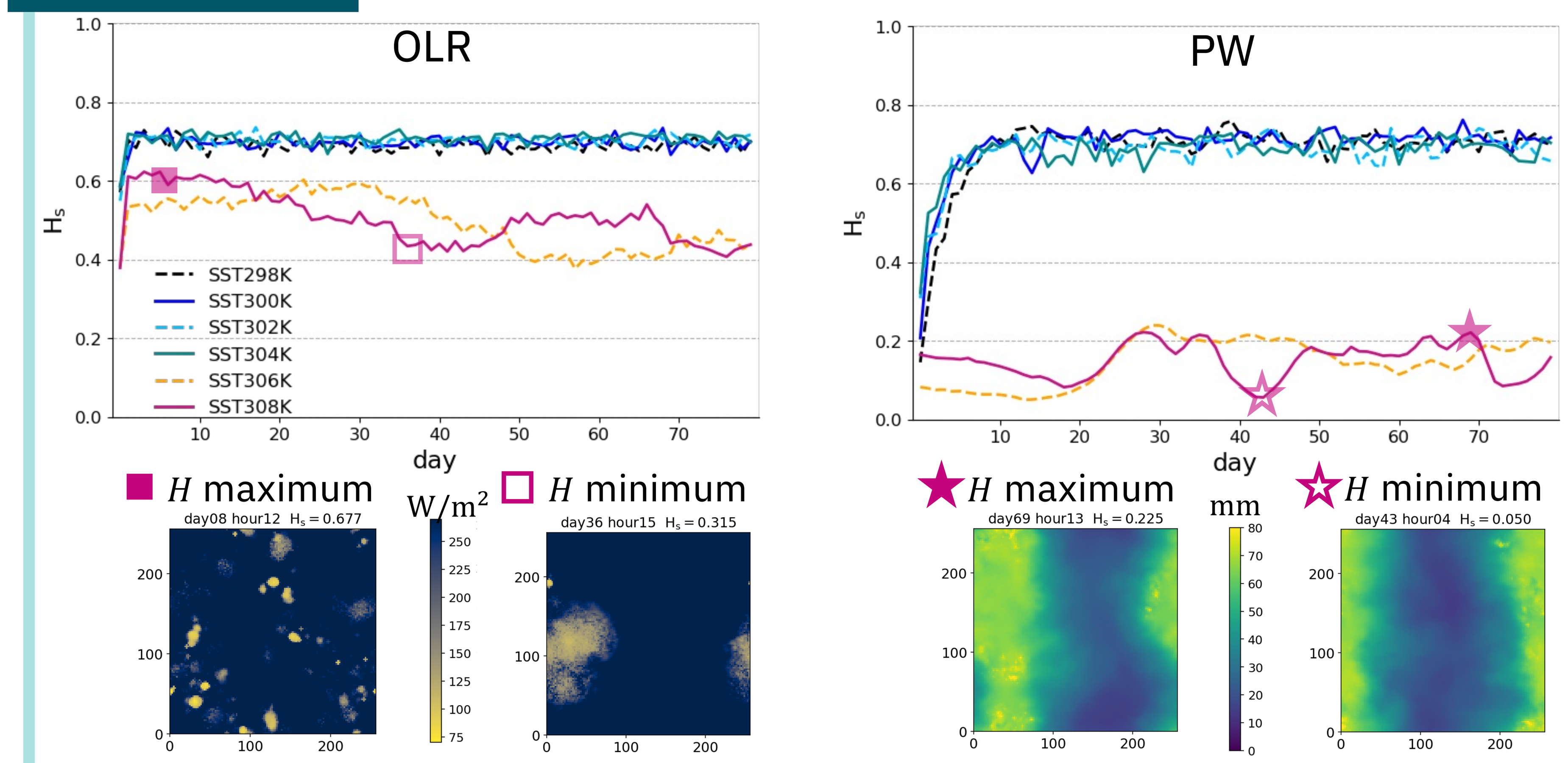
$$p_k(t) = \alpha_k|\psi_k(t)|^2 \Big/ \sum_{k=1}^{N} \alpha_k\,|\psi_k(t)|^2$$

2. PDF based on two-dimensional Fourier series spectrum

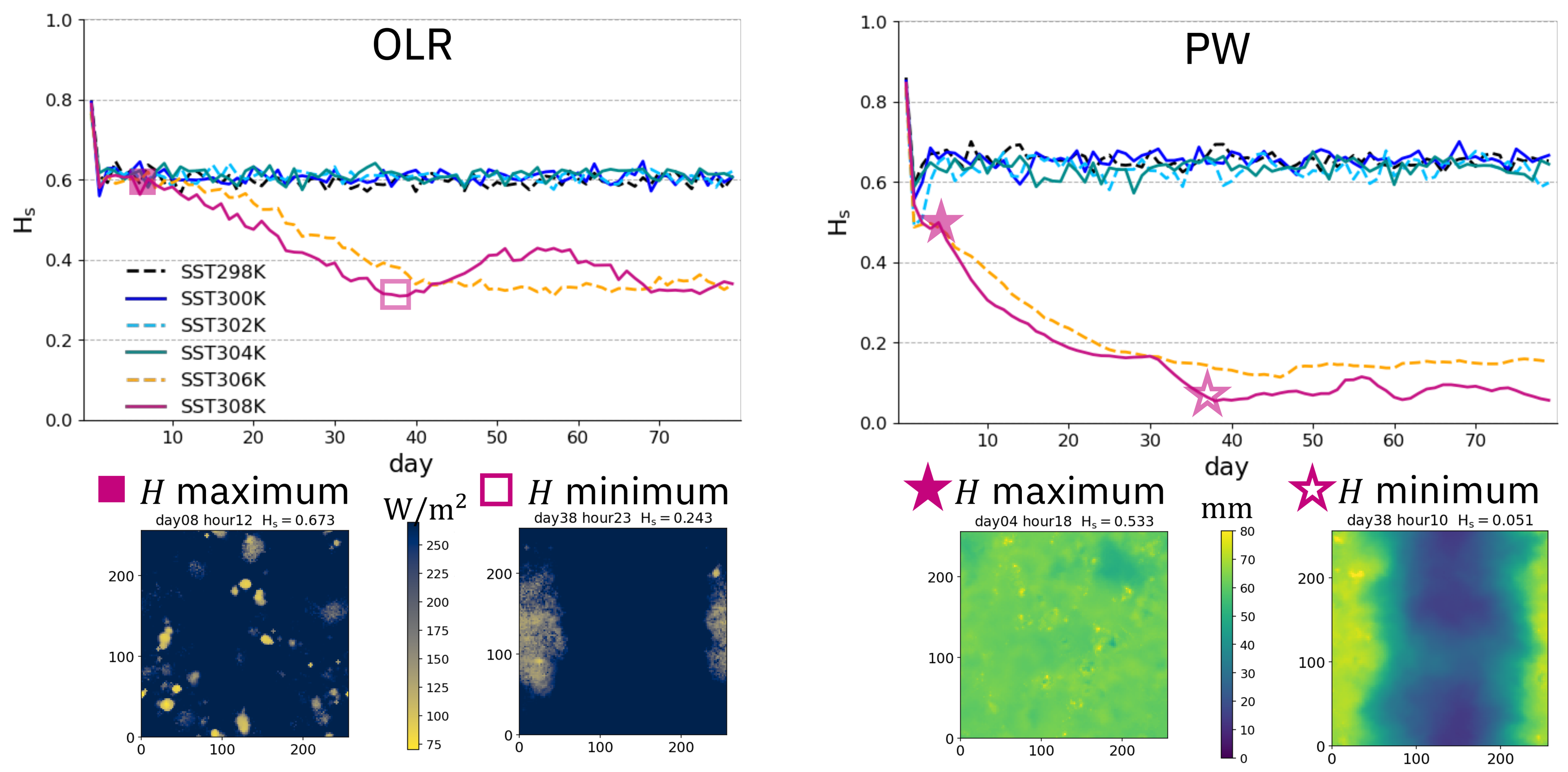
$$u(x,y) = \frac{1}{N}\sum_{x=1}^{N_x}\sum_{y=1}^{N_y} U(k,l)\exp\left[\frac{2\pi i}{N}(kx+ly)\right]$$

$$p_{k,l}(t) = |U(k,l)|^2 \Big/ \sum_{k=0}^{n}\sum_{l=-n}^{n} |U(k,l)|^2$$

Results



The values of information entropy in aggregated cases are low, but the values and the time evolution of cloud self-aggregation are not clearly corresponding.



The values of information entropy in aggregated cases are low and better correspondence between the values and formation of the convective region.

Conclusion

Shannon's information entropy was shown to correspond to the degree of cloud self-aggregation.

H in this study is an index that reflects the degree to which a small number of specific modes can explain the total variation when the spatio-temporal variation of clouds is decomposed into orthogonal modes.

This work was supported by JSPS KAKENHI Grant Number JP20J11246 and The 4th ANRI Fellowship.