Observational-based Stochastic Convection Parameterization

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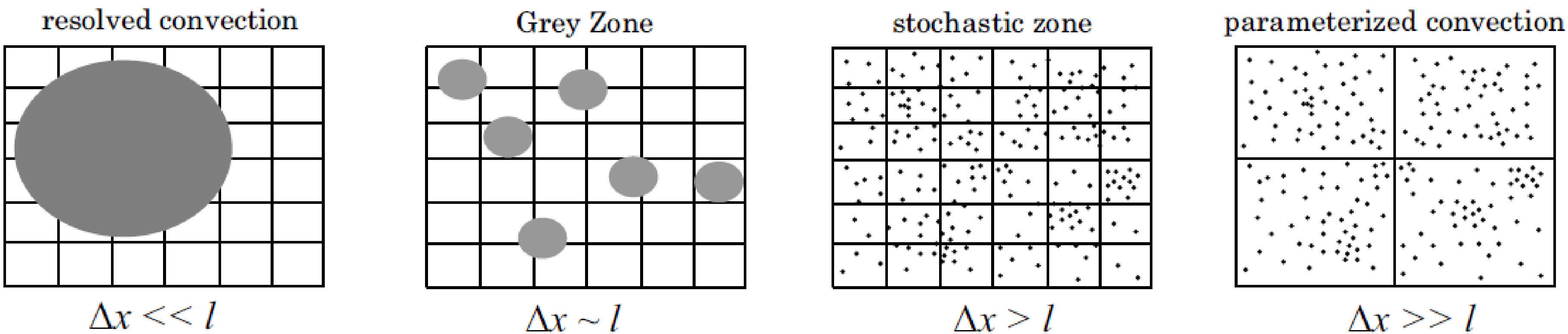
Outline

1. Motivation for stochastic convection;
2. High-resolution data or observations?
3. A multi-cloud model;
4. SPEEDY.

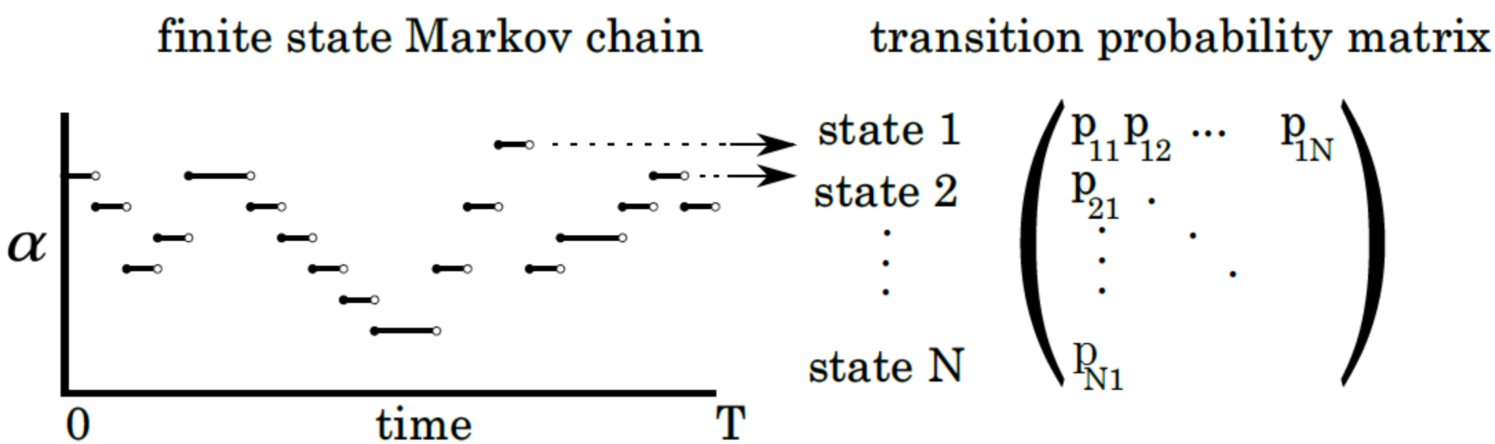
Introduction

- GCM resolutions tend to increase and are getting close to the Grey Zone;
- To be able to capture the increased variability related to convection, its representation should be stochastic;

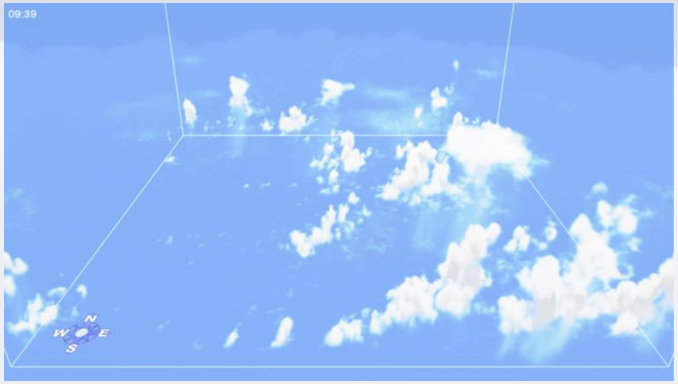


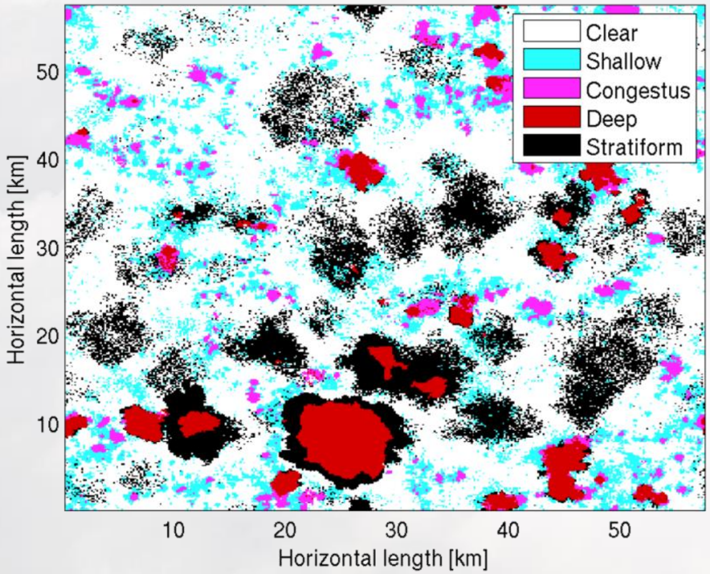
Introduction

- We make use of a stochastic multi-cloud model; This model is based on the multi-cloud model of Khouider et al. (2010);
- Transitions between cloud types are modeled with Markov chains that are conditioned on the large-scale state and the transition probabilities are estimated from data; Crommelin and Vanden-Eijnden (2008);
- Convective area fractions serve as a closure for the mass flux at cloud base;

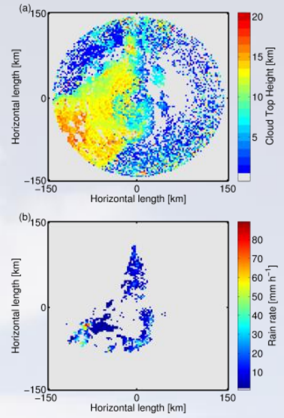


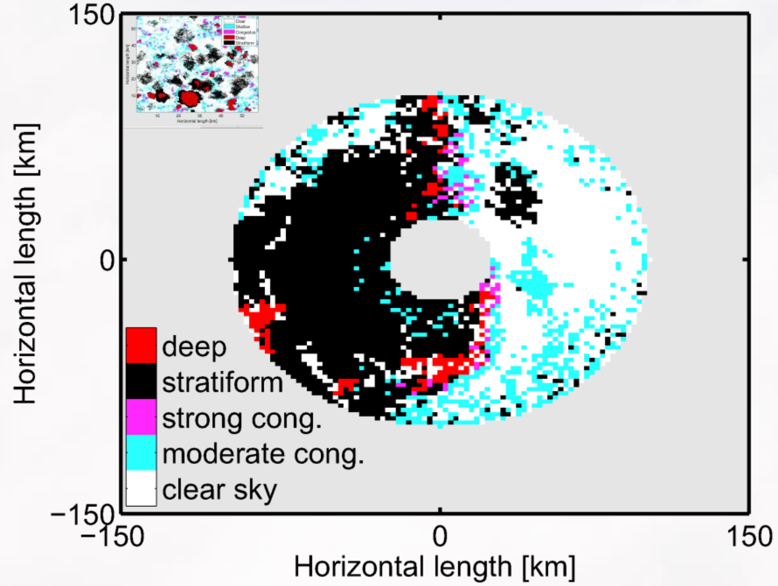
High-resolution **simulation**



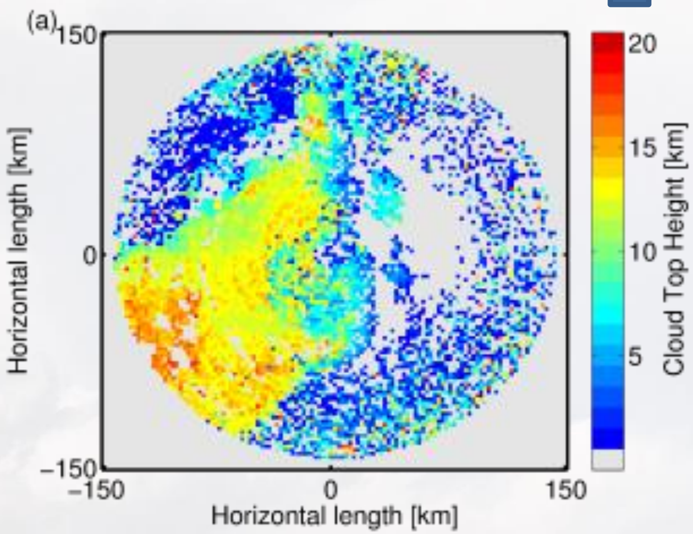


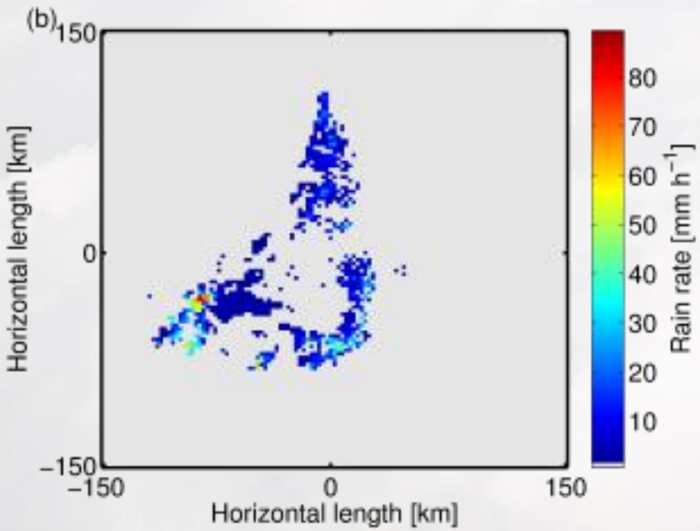
High-resolution **observations**



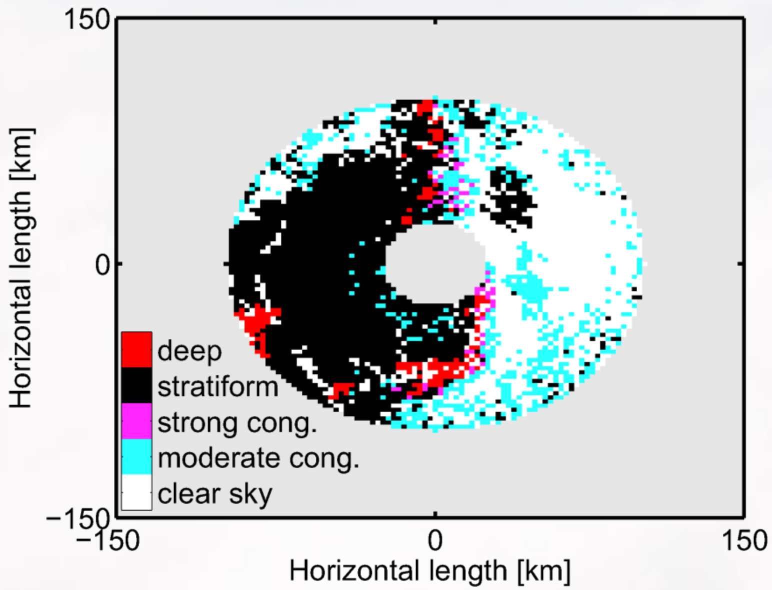


Classification

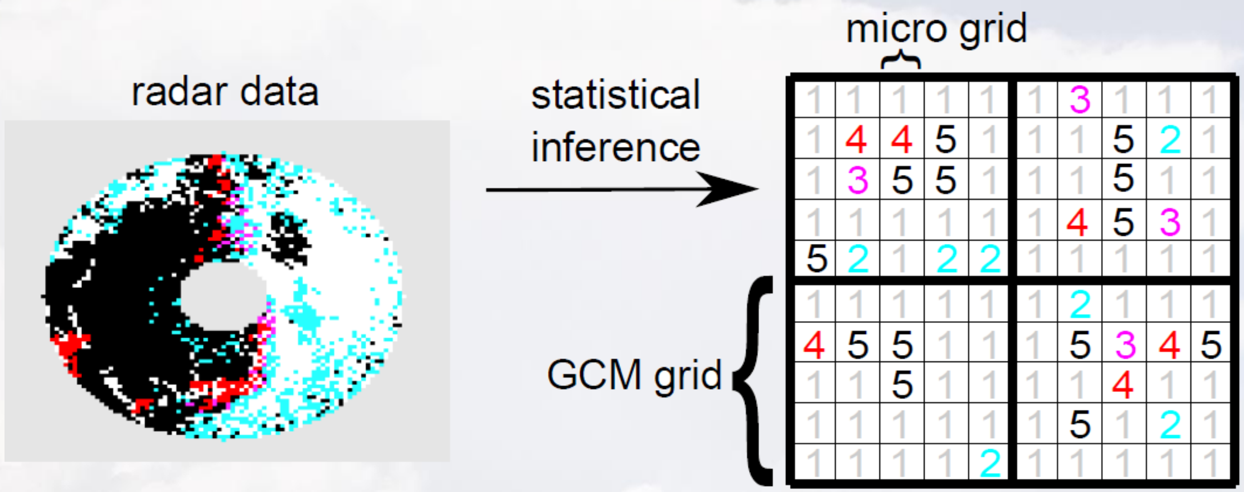




CTH [km]	rain rate [mm h^{-1}]	
	≤ 12	> 12
≥ 6.5	stratiform ($m = 5$)	deep convective ($m = 4$)
	≤ 3	> 3
$\in [1.5, 6.5)$	moderate congestus ($m = 2$)	strong congestus ($m = 3$)
< 1.5	clear ($m = 1$)	



Stochastic multi-cloud model



cloud types:

1 = clear sky

2 = moderate congestus

3 = strong congestus

4 = deep convective cloud

5 = stratiform cloud

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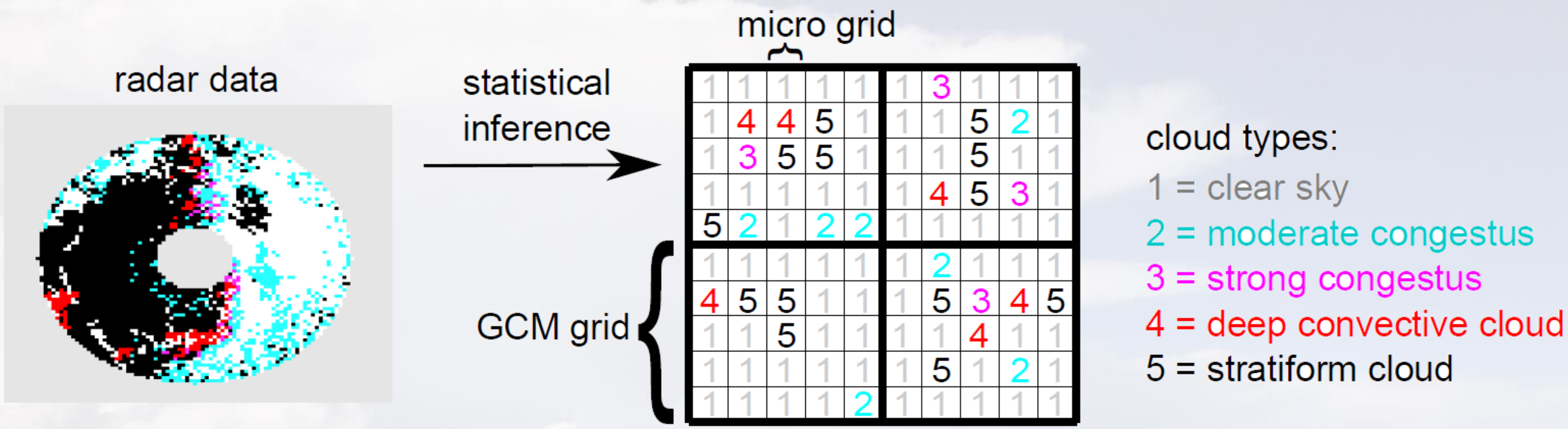

- Transition probability matrix
- ΔT =10 min
- Compensated for advection

$$\hat{\mathbf{M}} = \begin{pmatrix} 0.8987 & 0.0668 & 0.0006 & 0.0011 & 0.0329 \\ 0.4147 & 0.4707 & 0.0033 & 0.0026 & 0.1086 \\ 0.2563 & 0.2686 & 0.2177 & 0.0545 & 0.2029 \\ 0.1757 & 0.0284 & 0.0124 & 0.4295 & \mathbf{0.3540} \\ 0.1185 & 0.0779 & 0.0010 & 0.0091 & 0.7935 \end{pmatrix}$$

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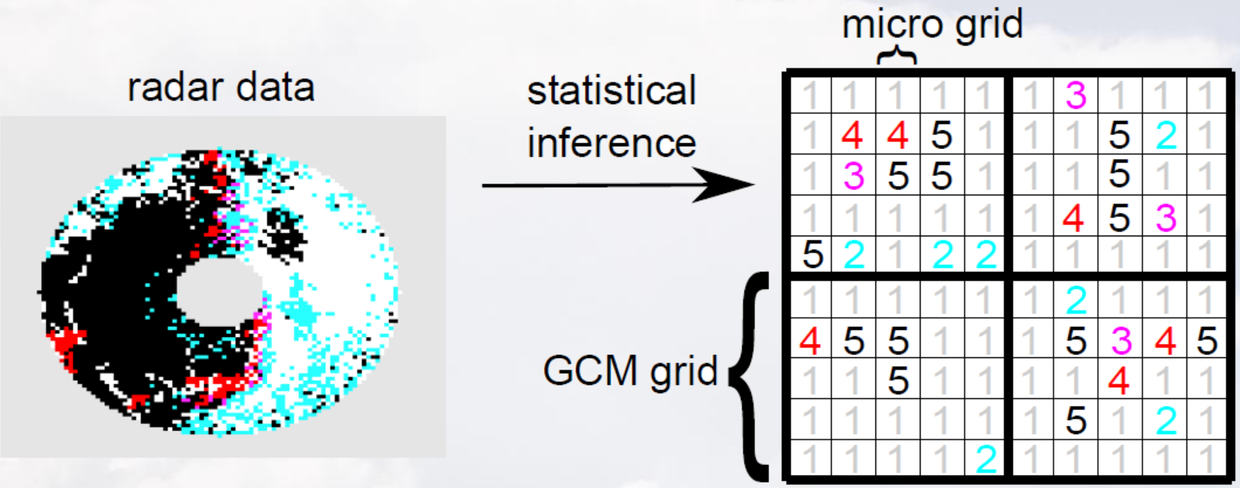

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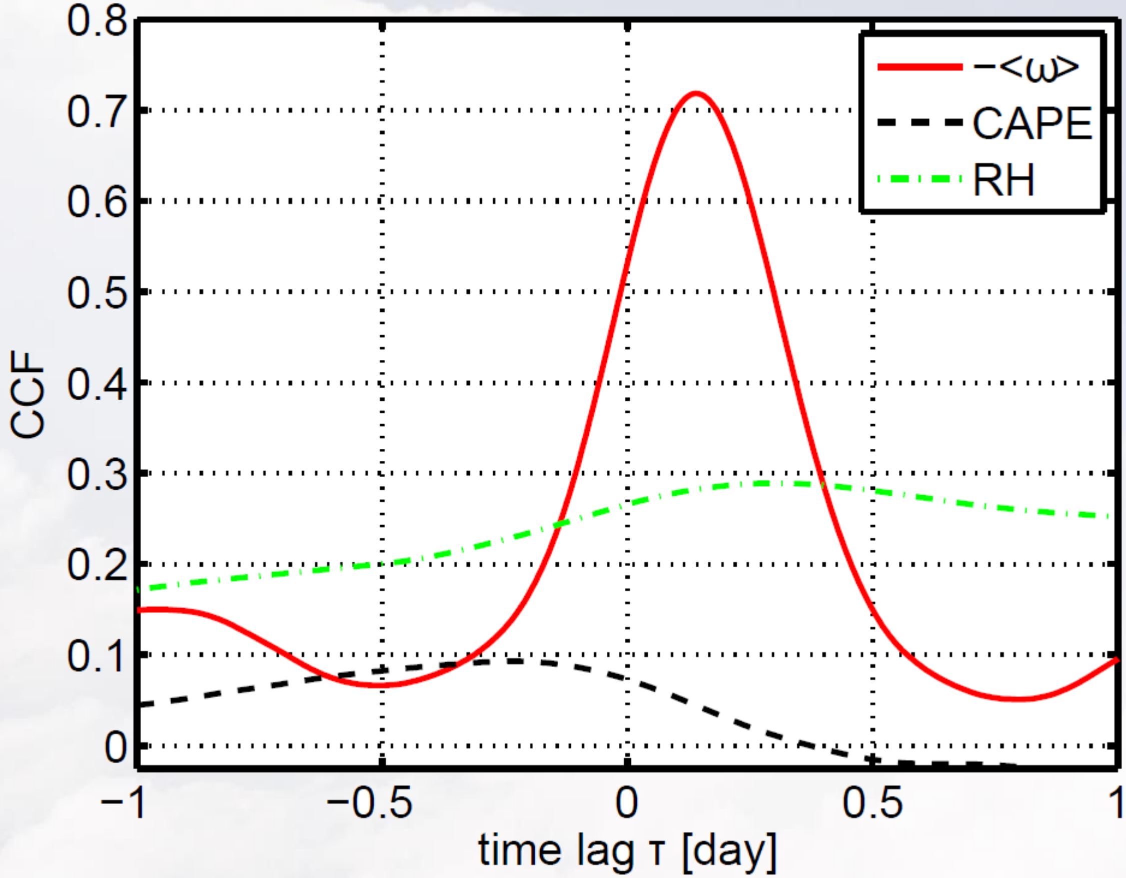
- Cloud type area fractions calculated for each GCM column

$$\sigma_m(t) = \frac{1}{N}\sum_{n=1}^{N} \mathbf{1}[Y_n(t) = m],$$

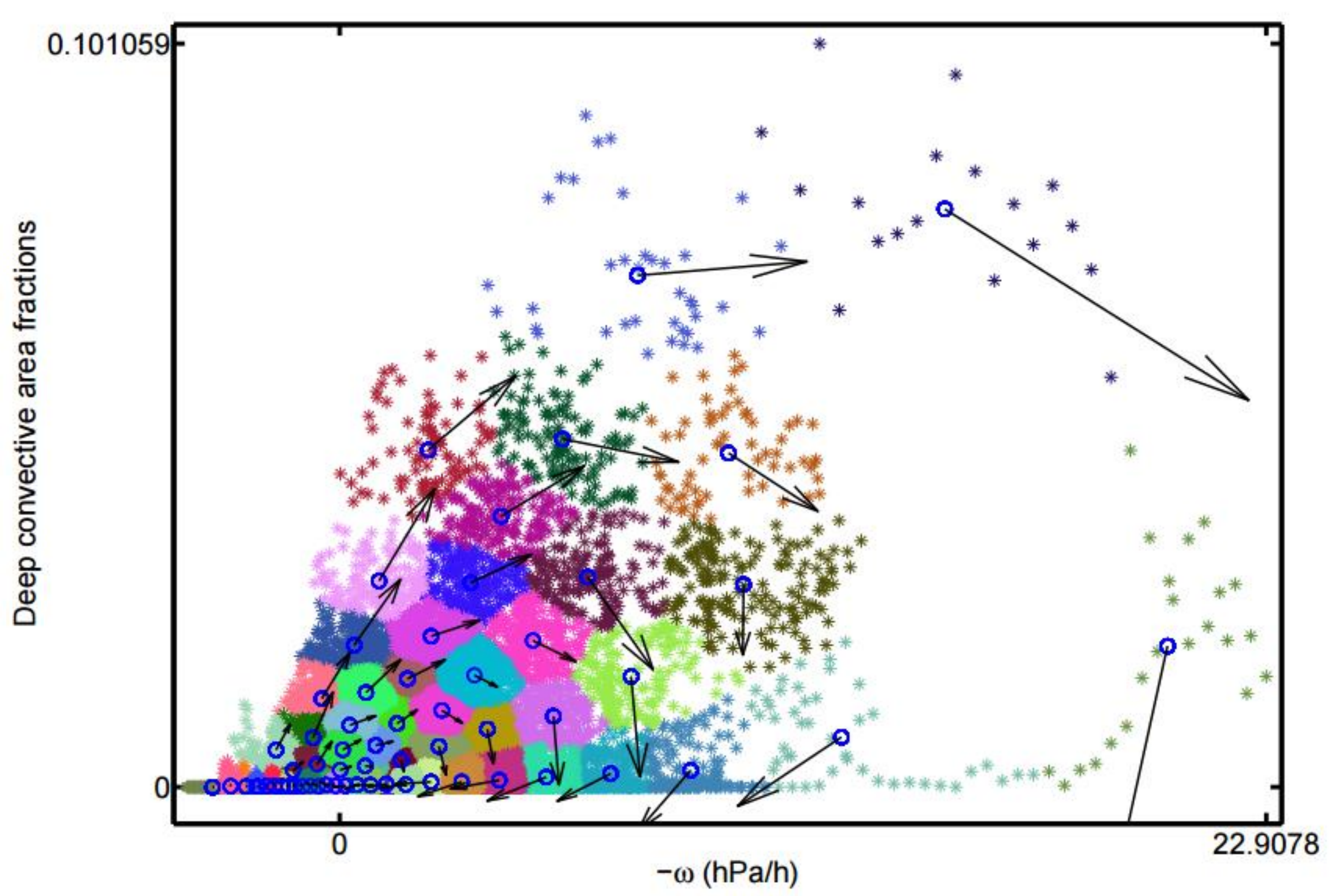
Cross-Correlation analysis



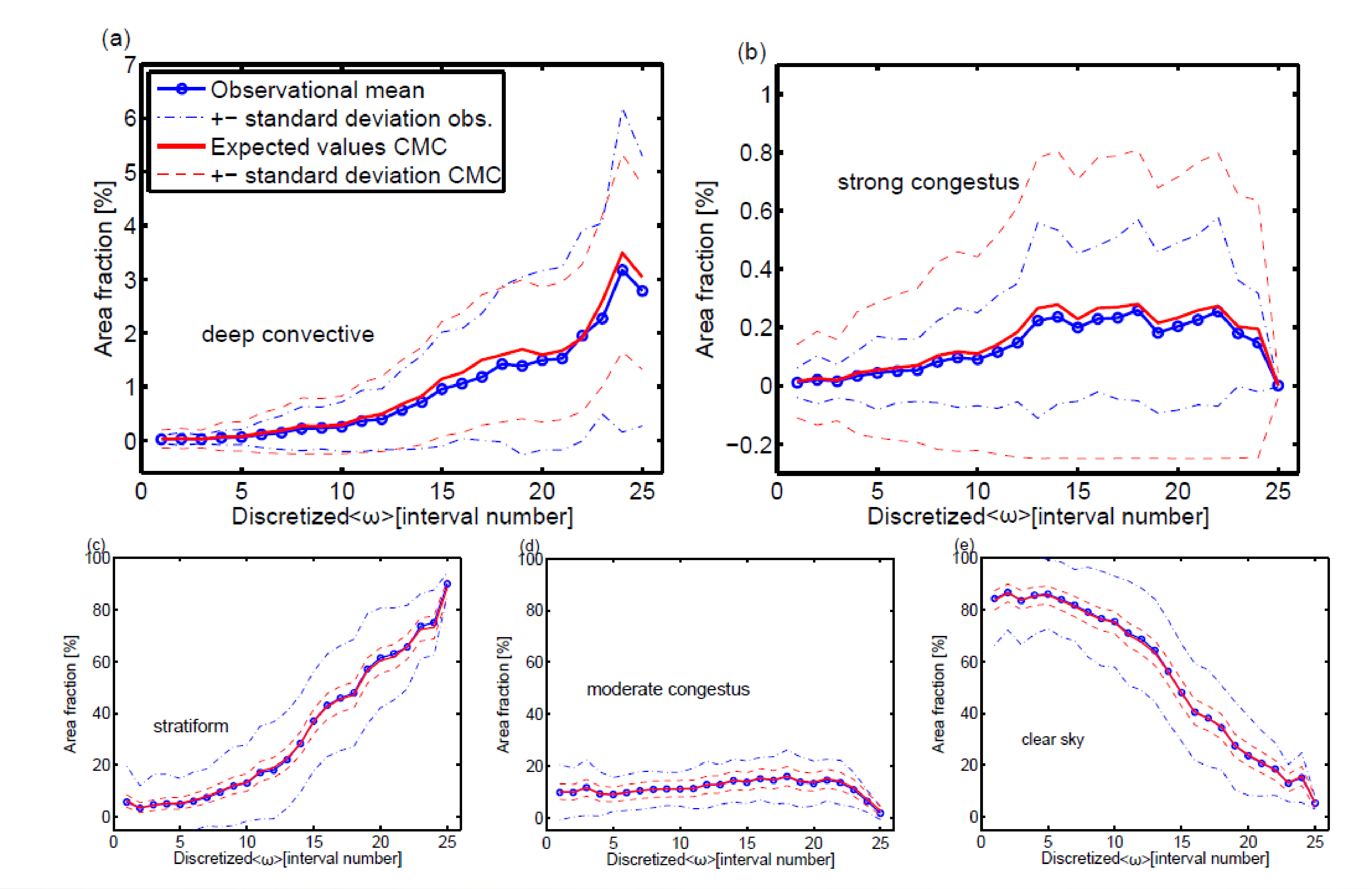
$$\mathrm{CCF}(\tau) = \int_{-\infty}^{\infty} \tilde{X}(t+\tau)\tilde{\sigma}_4(t)dt$$

$$\tilde{X}(t) = \frac{X(t)-\mu_X}{\sigma_X} \qquad \langle\omega\rangle := \frac{1}{p_0 - p^*}\int_{p^*}^{p_0} \overline{\omega}(p)dp$$

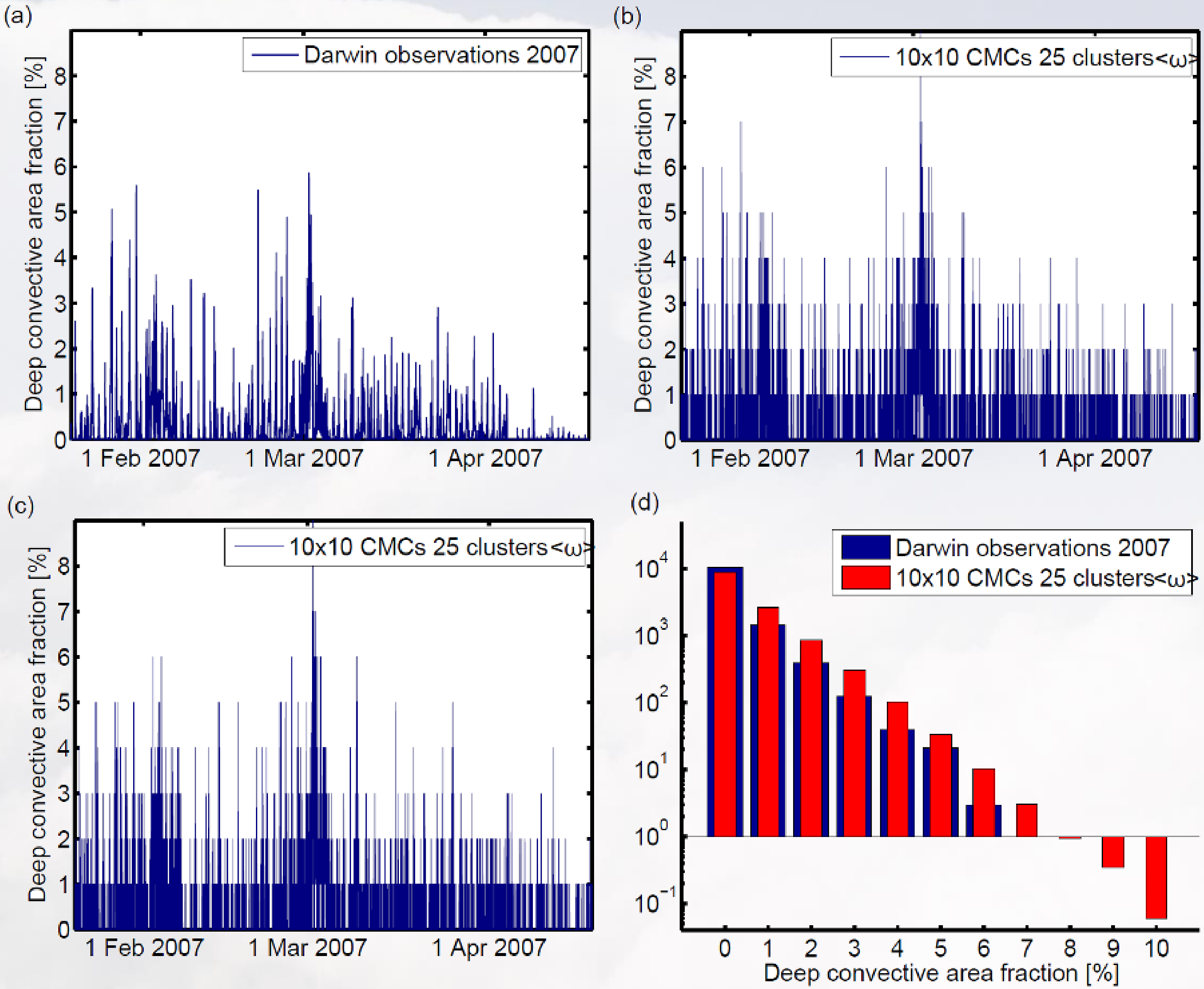
Relation omega sigma



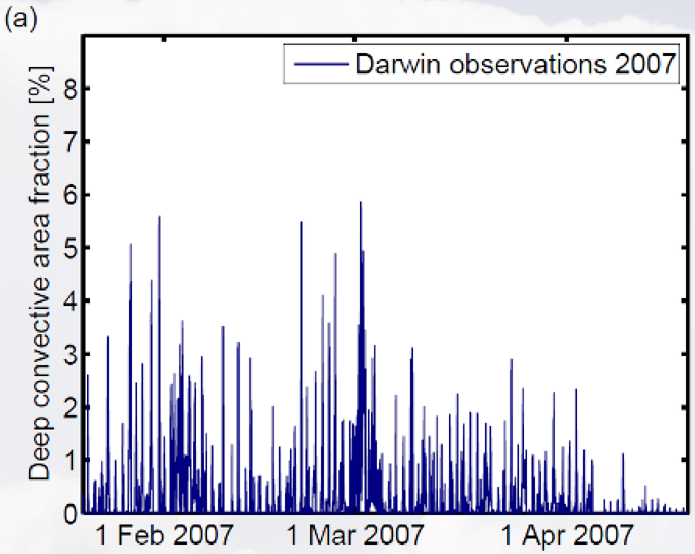
Conditioning on the large-scales variables

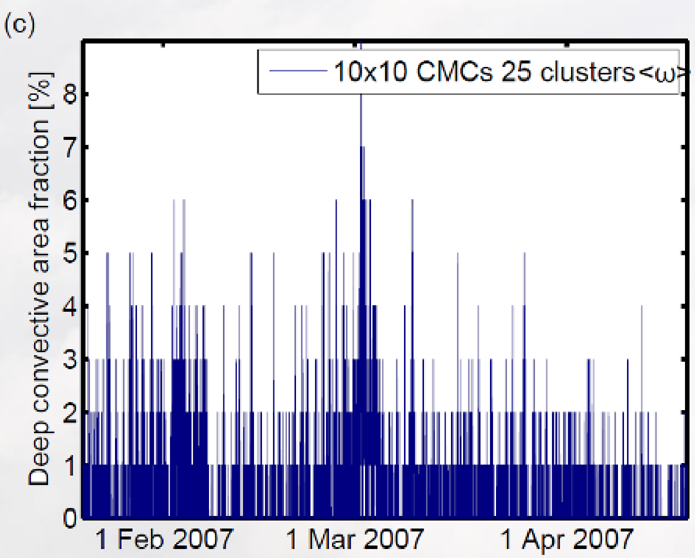


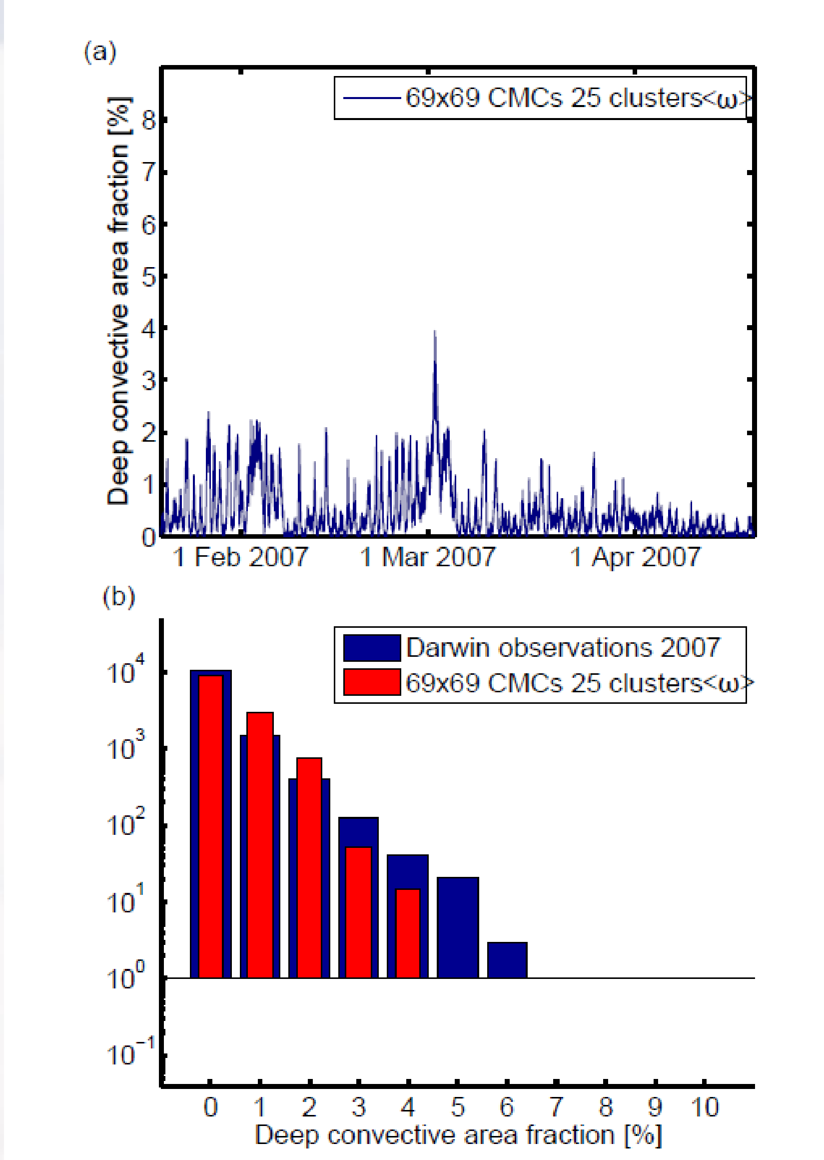
Convective area fractions



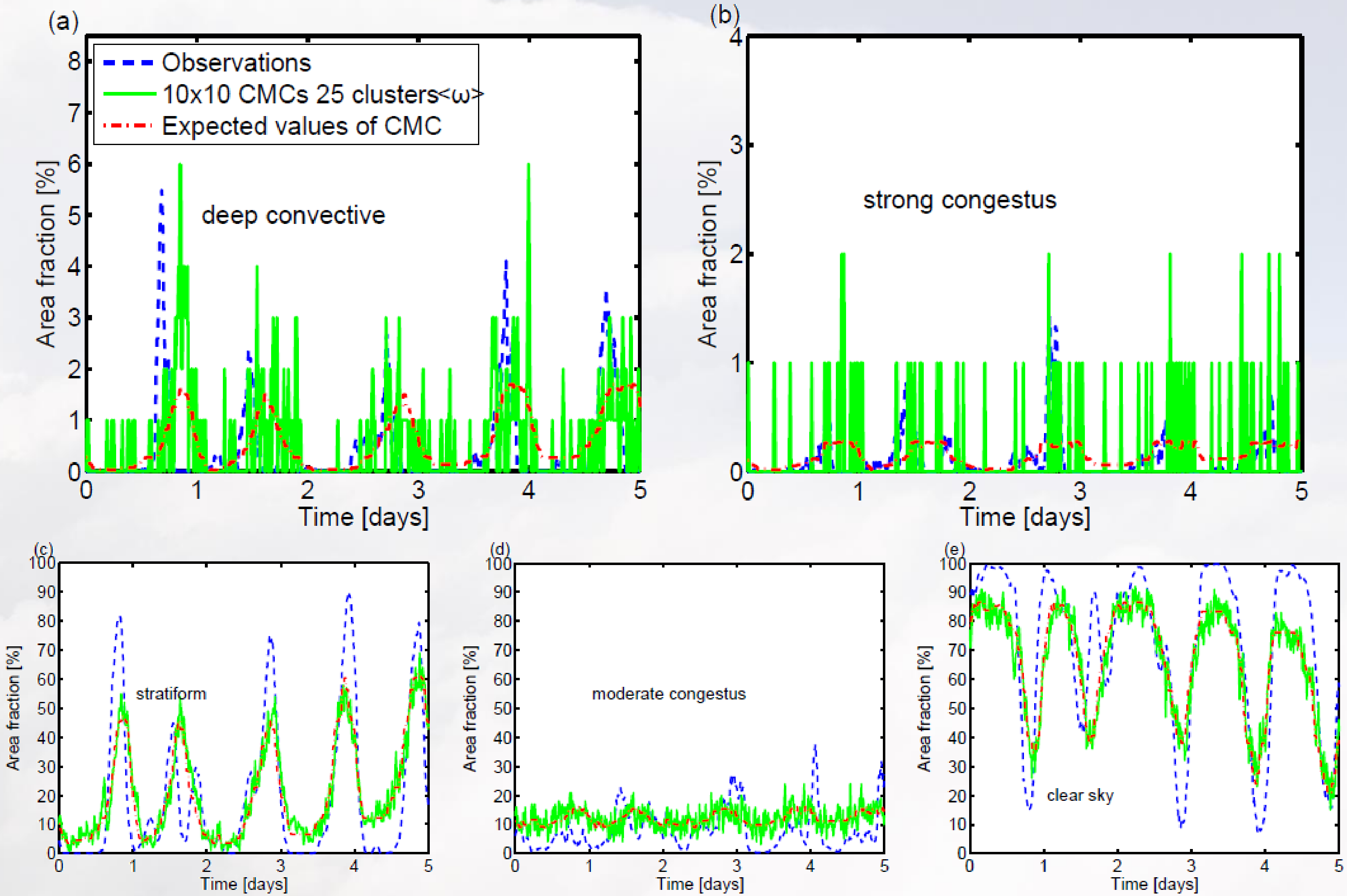
Scale-adaptivity







Cloud type area fractions

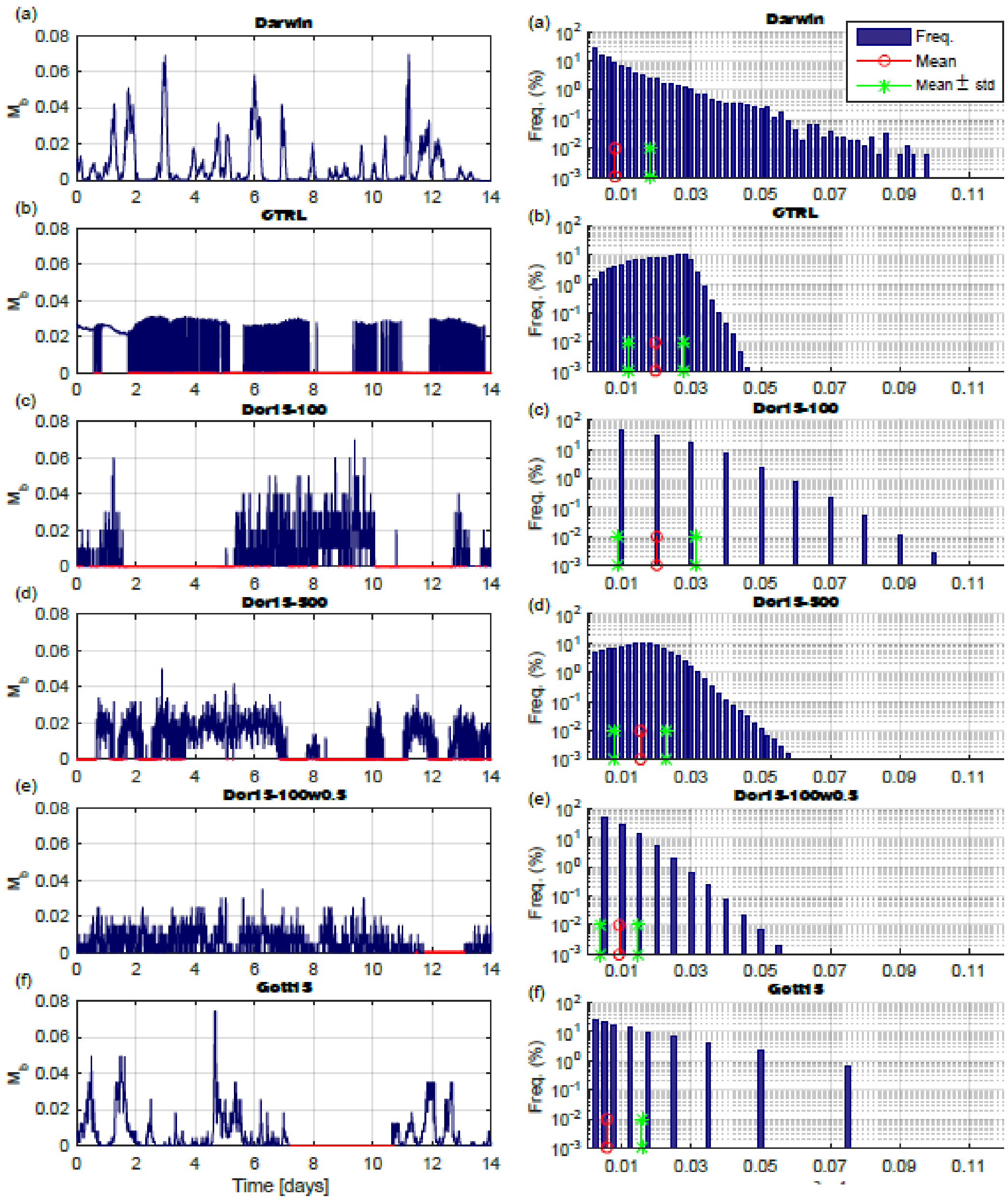


Implementation in SPEEDY

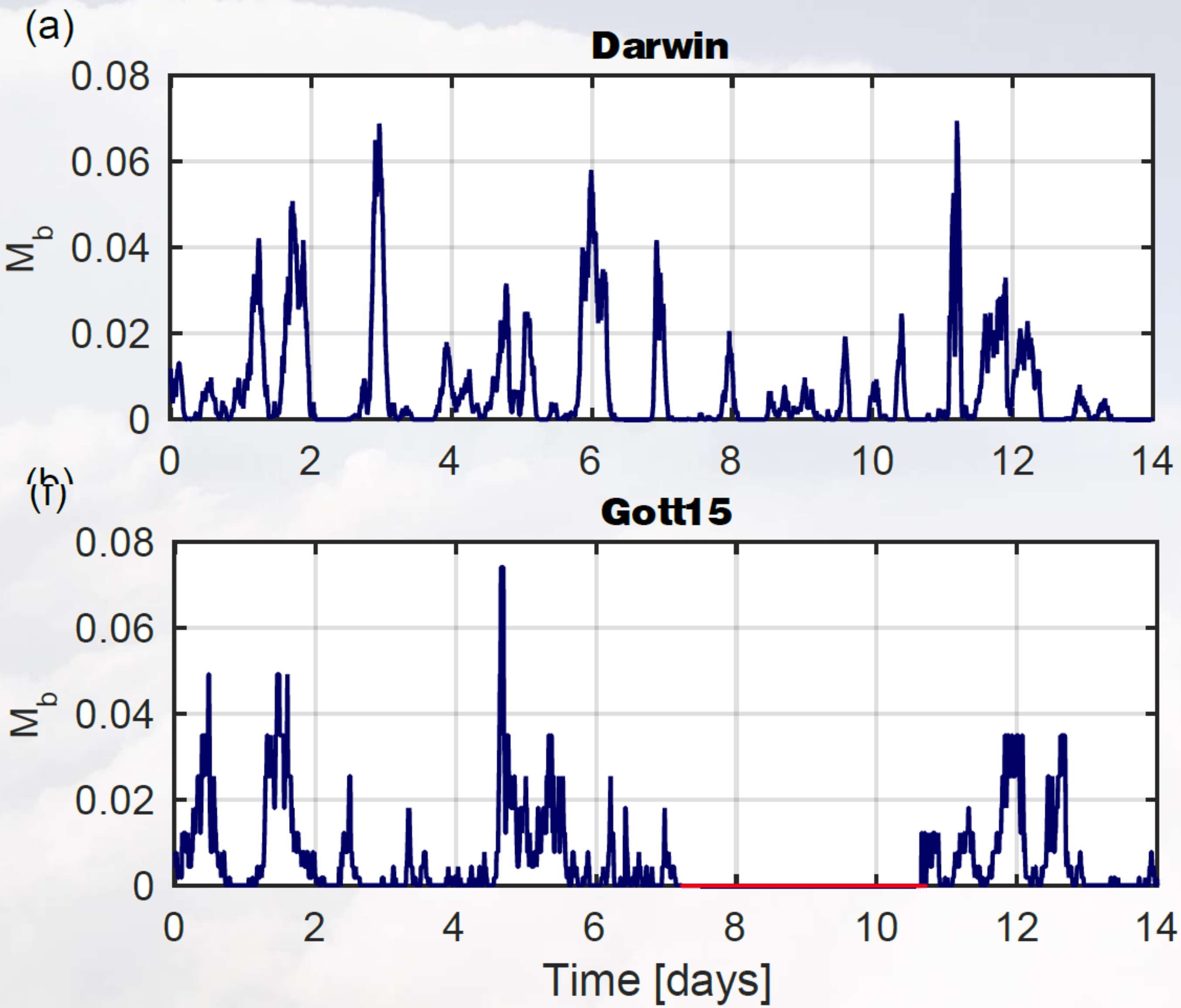
- SPEEDY is a GCM of intermediate complexity;
- It is a hydrostatic spectral model solving the primitive equations on the entire globe;
- T30 resolution or 3.75 x 3.75 degree; 8 z-levels;
- SSTs are prescribed;
- Seasonale cycle; no daily cycle;
- Shallow convection: vertical diffusion;
- Convection: simplified Tiedtke mass flux scheme; Use convective area fractions as a closure for the mass flux at cloud base.

$$M_b = \rho w_c \sigma_c ,$$

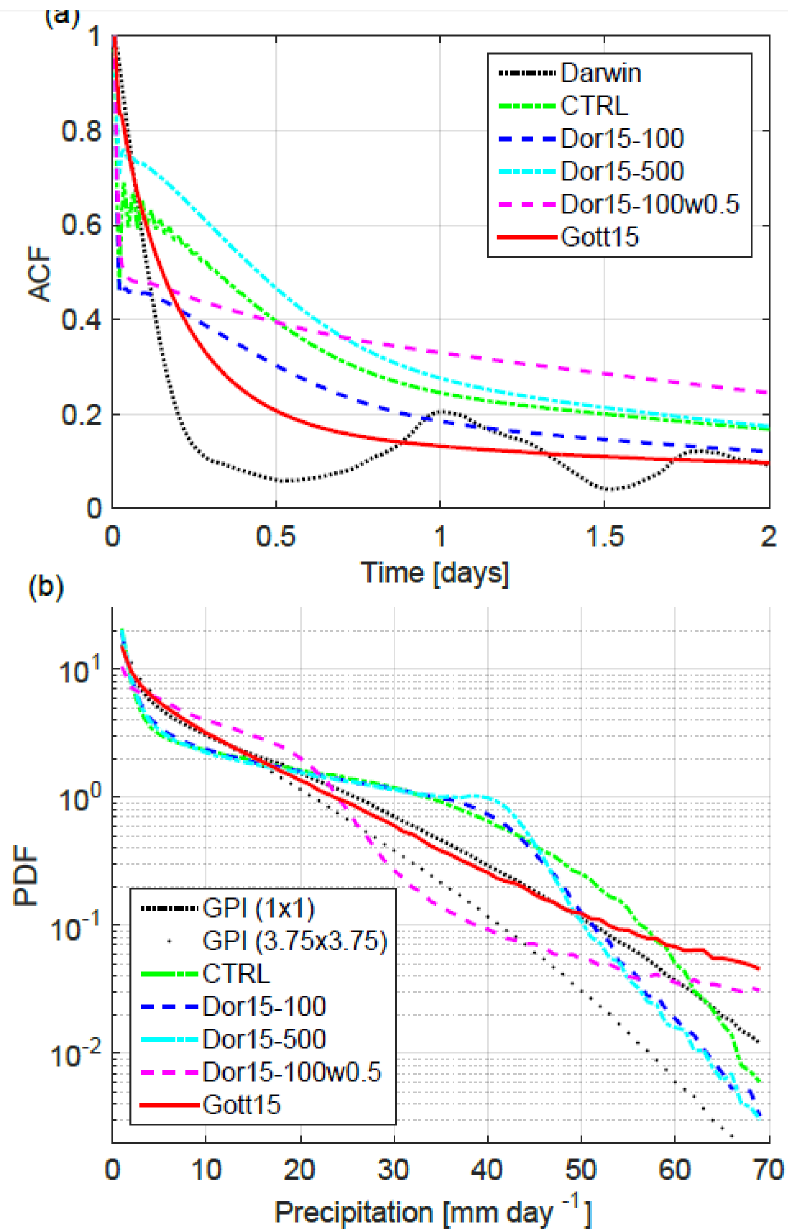
Mass flux at cloud base



Mass flux at cloud base

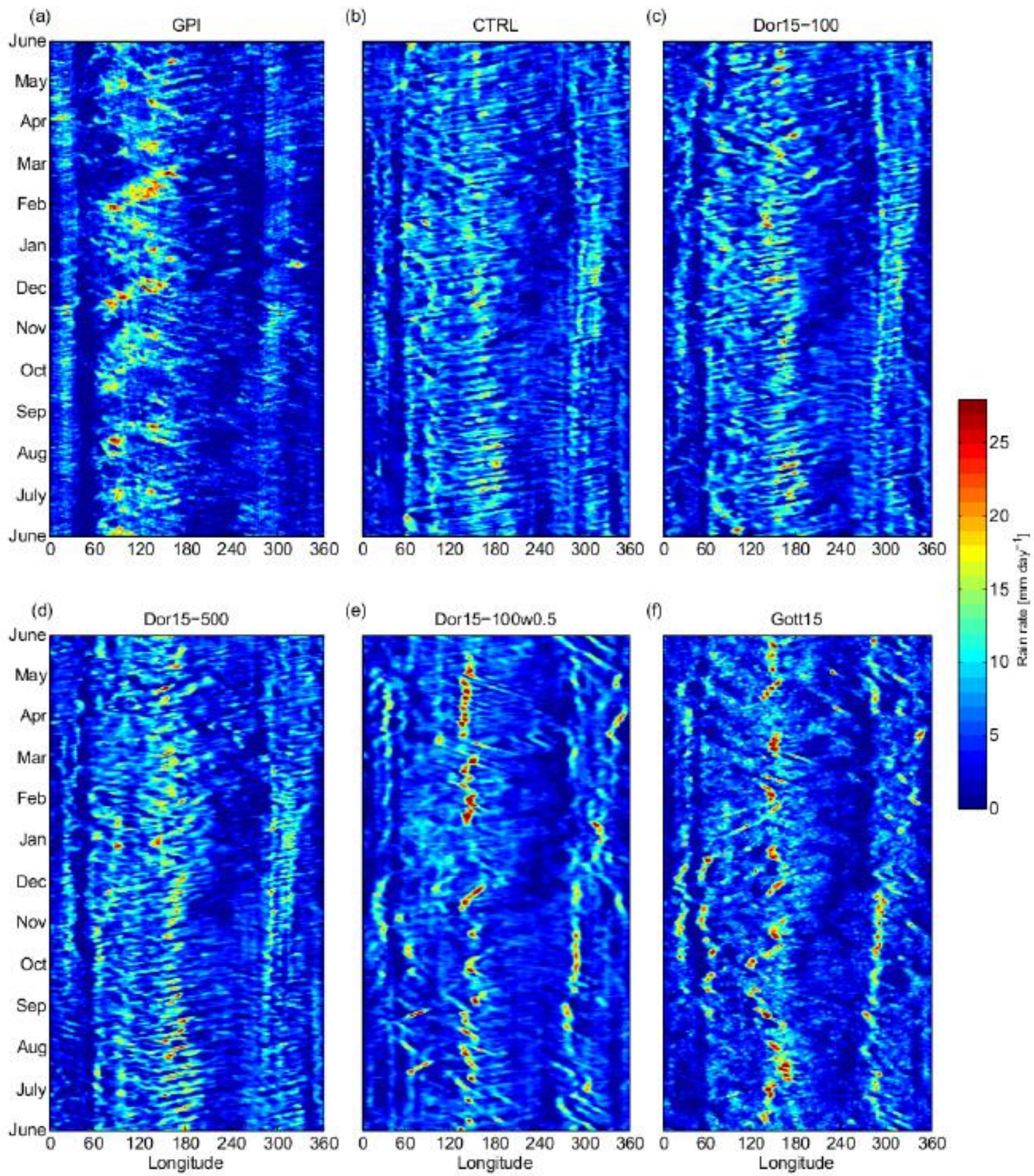


ACF and PDF

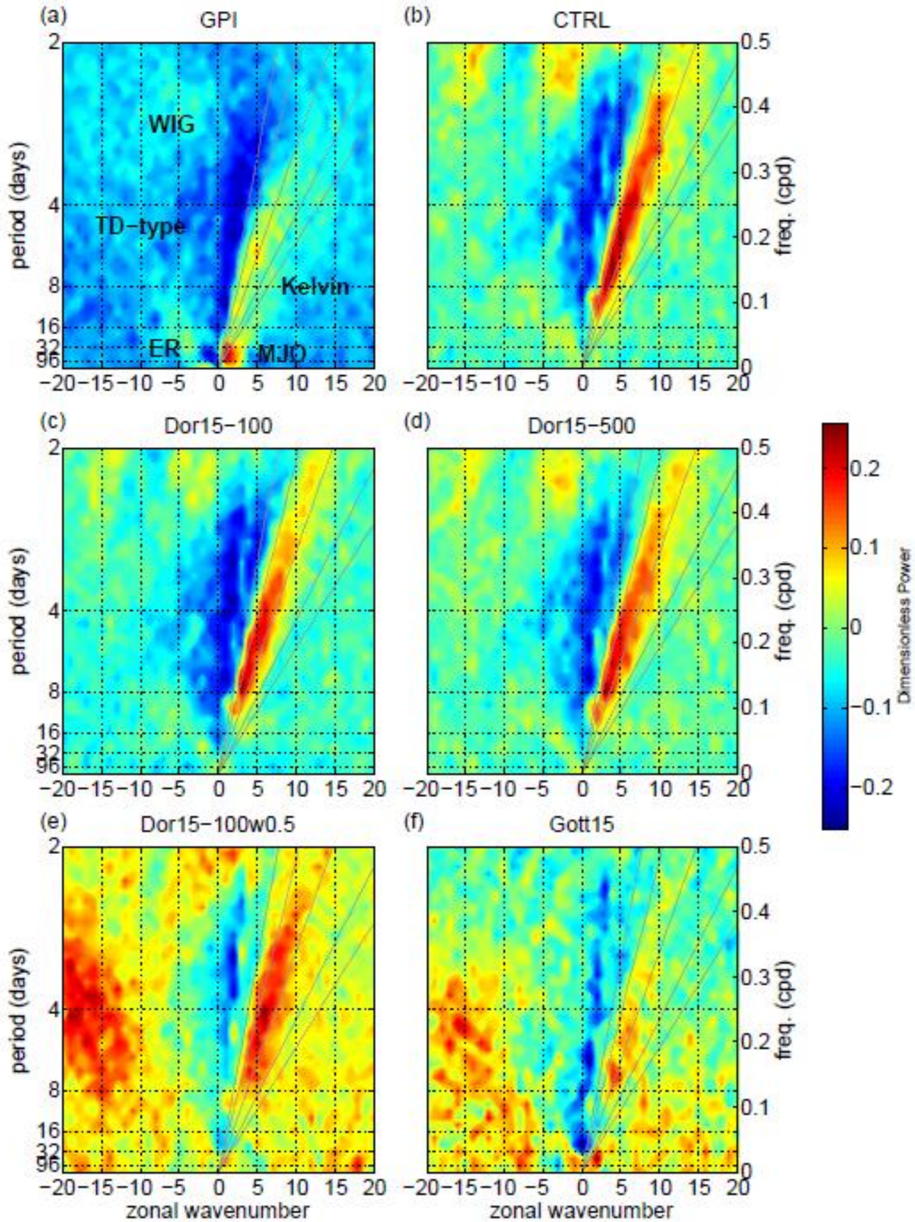


(a)
ACF
Time [days]
Darwin
CTRL
Dor15-100
Dor15-500
Dor15-100w0.5
Gott15
(b)
PDF
Precipitation [mm day -1]
GPI (1x1)
GPI (3.75x3.75)
CTRL
Dor15-100
Dor15-500
Dor15-100w0.5
Gott15

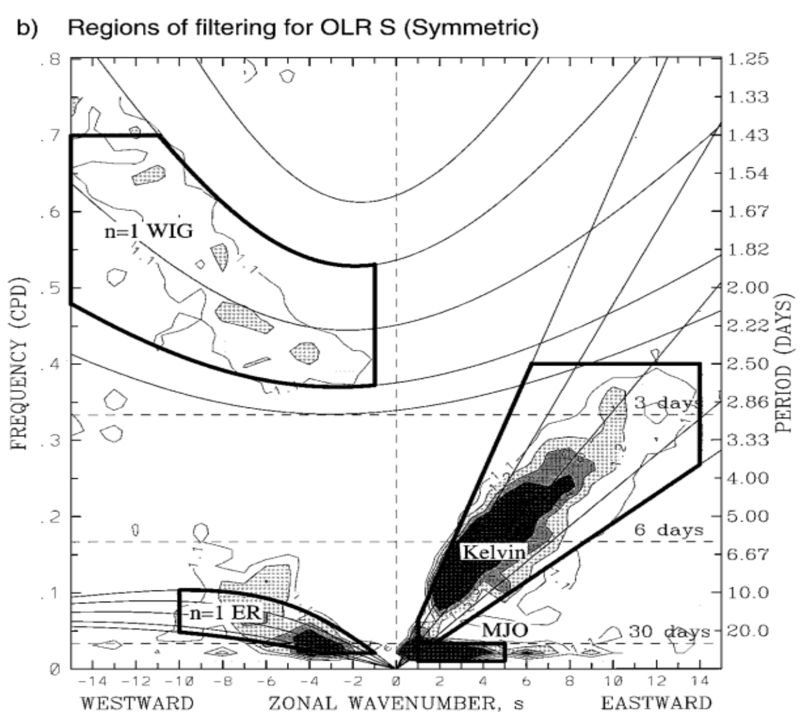
Hovmöller-diagrams

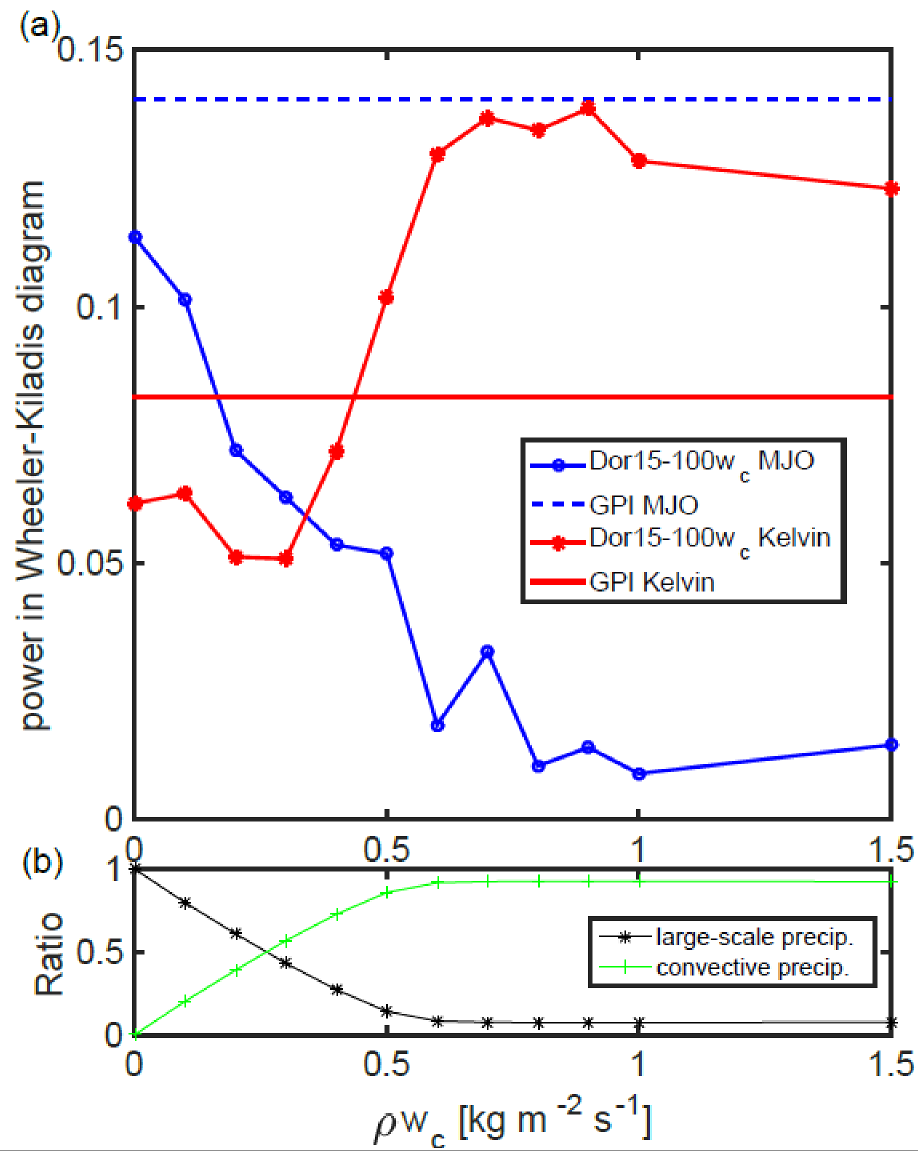


Wheeler-Kiladis diagrams



Kelvin and MJO power





Summary

- The stochastic multi-cloud model captures variability related to convection;
- Observations more useful than LES (at the moment);
- Multi-cloud model is scale-aware;
- The large-scale vertical velocity omega displays the largest correlation with deep convection;
- By conditioning on omega, realistic time-series of the mass flux at cloud base are generated in SPEEDY;
- The scheme similar to Gottwald et al. (2016) improves the PDF of the daily accumulated precipitation and the ACF;
- The average strength of the mass flux at cloud base affects the simulation of MJO and Kelvin waves;
- By calculating the average wave power, the skill of simulation of equatorial waves can be expressed in a single scalar; this method can be used to tune models.

References

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