ARCCSS Maritime Continent Workshop
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IMAS INSTITUTE FOR MARINE AND ANTARCTIC STUDIES

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Predictability of the MJO index: Seasonality and phase-dependence

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translating**nature**into**knowledge**

The Madden-Julian Oscillation

- The **Madden-Julian Oscillation (MJO)** is dominant mode of intraseasonal (30-90 day) variability in the Tropics
- Expressed as
  - Deep convection, cloud cover
  - Rainfall
  - Low- and high-level winds
- Develops over Indian Ocean and propagates eastward, 5-10 m/s
- Influences generation of tropical cyclones, sea level variations, extratropical air temperature, etc…

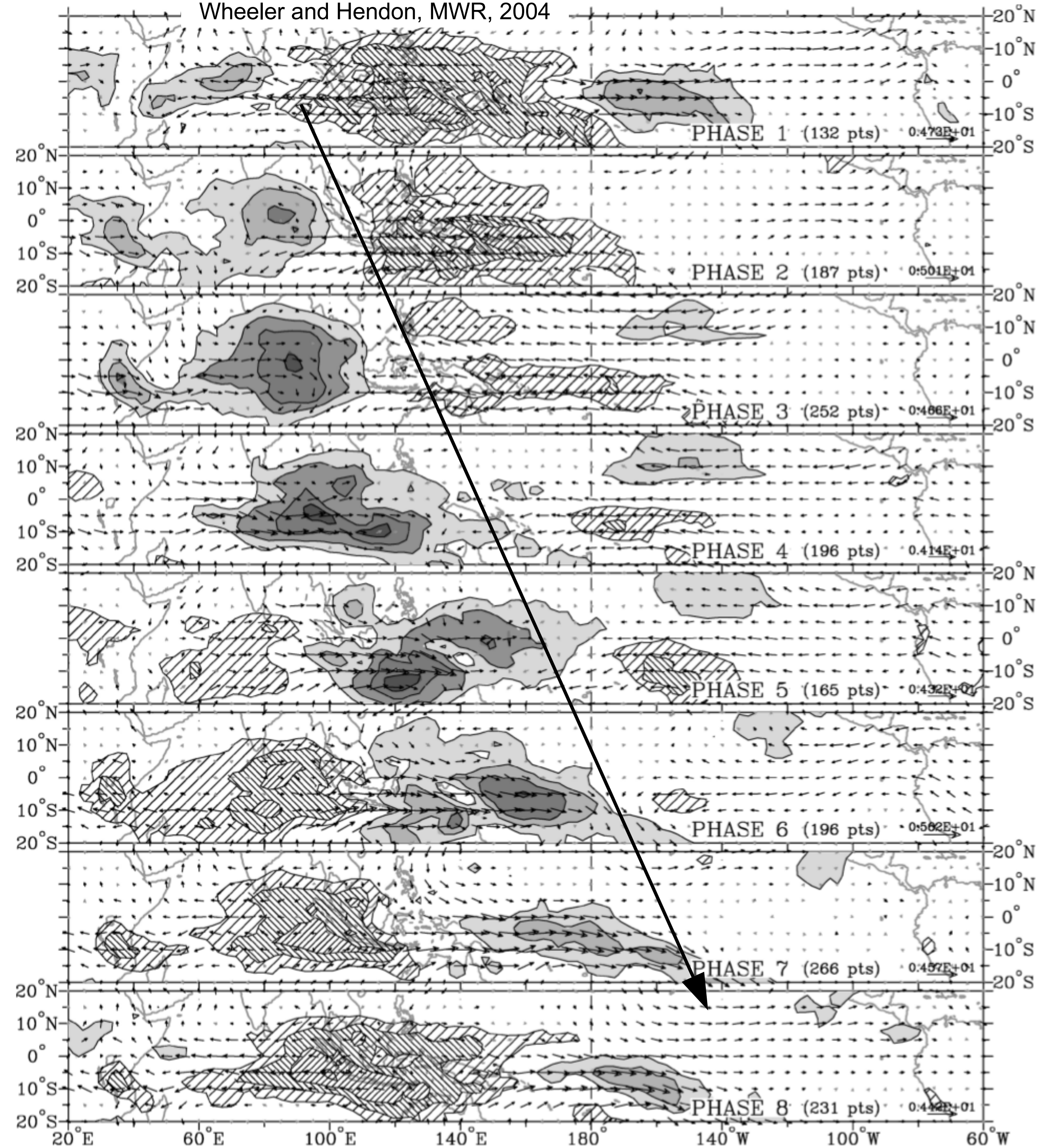
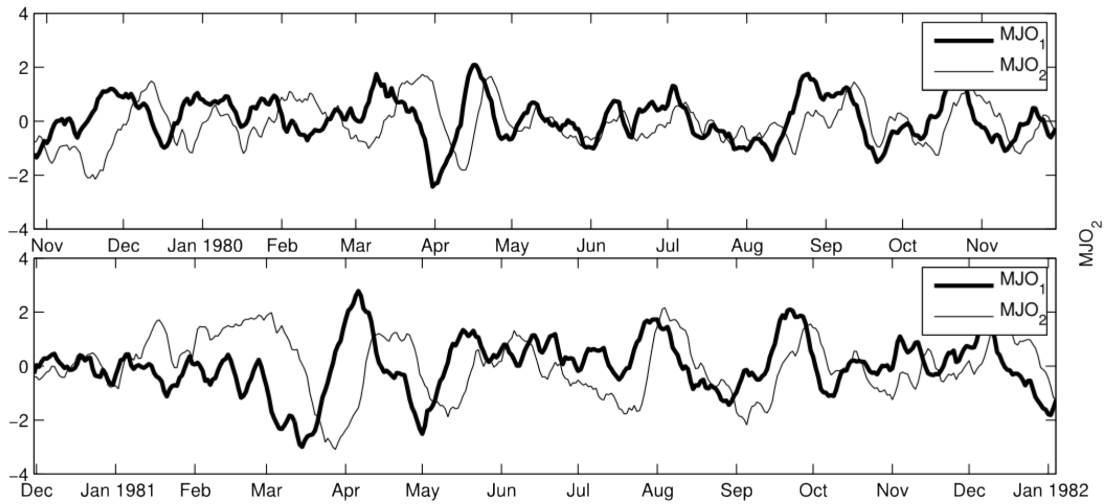


FIG. 8. DJF composite OLR^A and 850-hPa wind vector anomalies. Shading levels denote OLR anomalies less than −7.5, −15, −22.5, and −30 W m^{-2}, respectively, and hatching levels denote OLR anomalies greater than 7.5, 15, and 22.5 W m^{-2}, respectively. Black arrows indicate wind anomalies that are statistically significant at the 99% level, based on their local standard deviation and the Student's t test. The magnitude of the largest vector is shown on the bottom right, and the number of days (points) falling within each phase category is given.

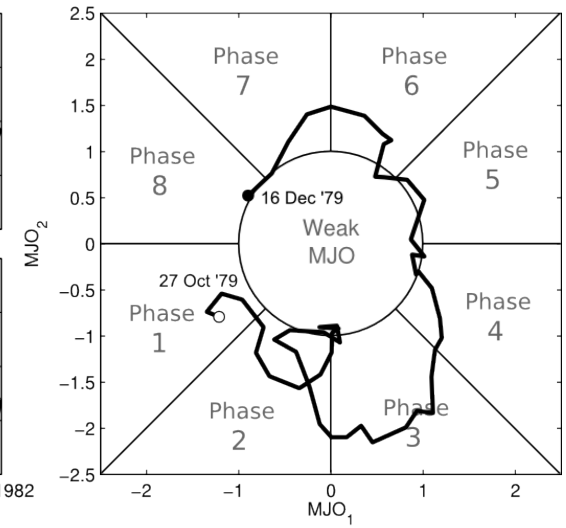
The Madden-Julian Oscillation

- Wheeler and Hendon (2004) (or WH04) **MJO index** based on 2 PCs of intraseasonal outoing longwave radiation (OLR), and zonal wind at 200 hPa and 850 hPa:

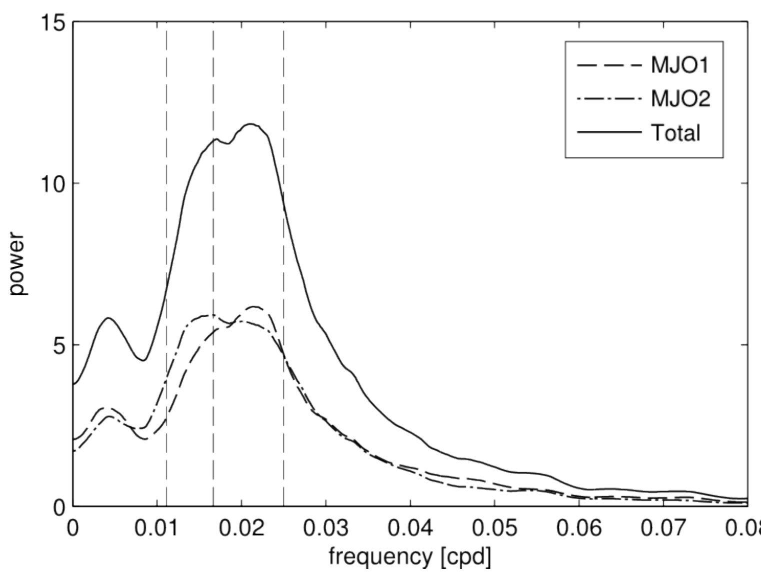
MJO index: Components 1 (—) and 2 (—)



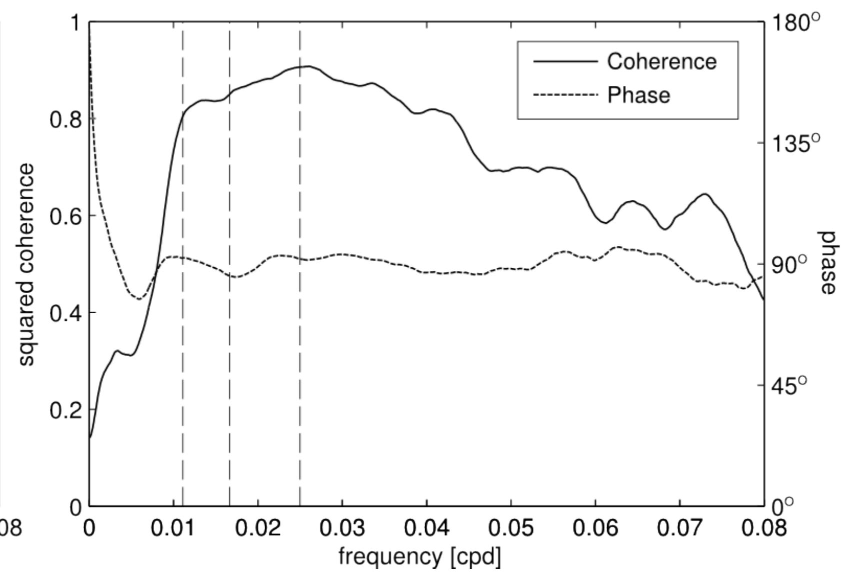
MJO Phase Space



MJO index power spectra



MJO index coherence and phase spectra



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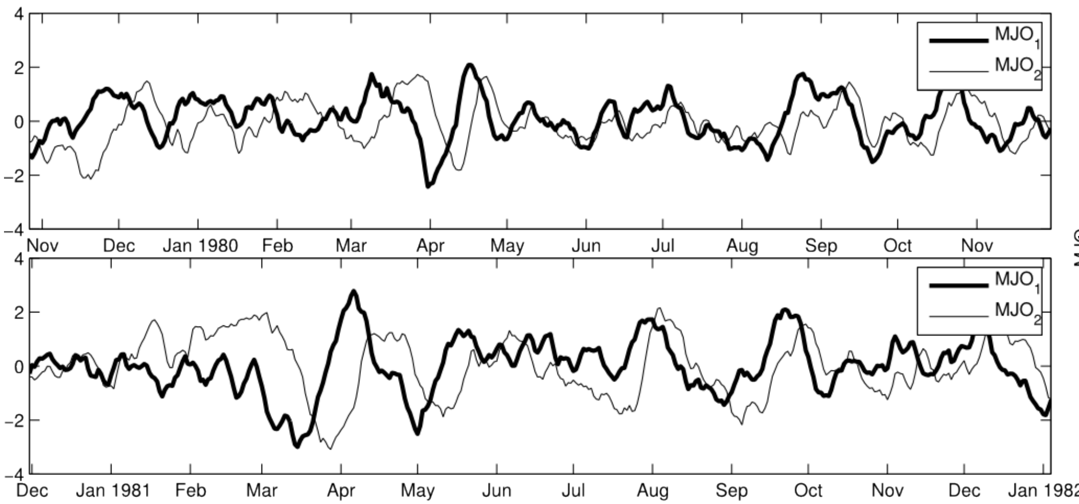

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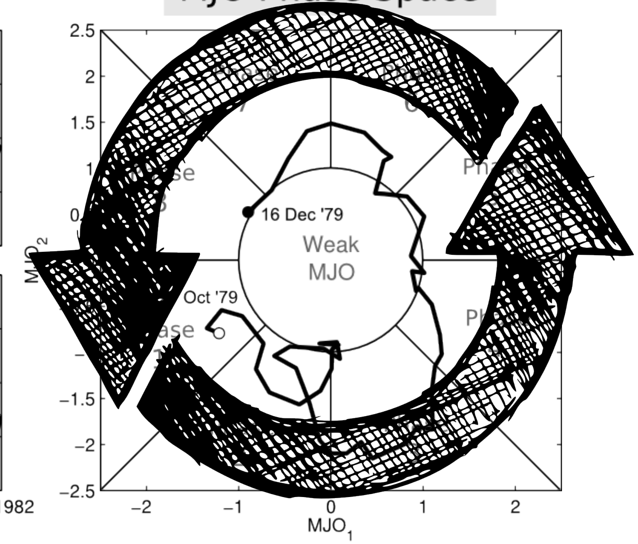

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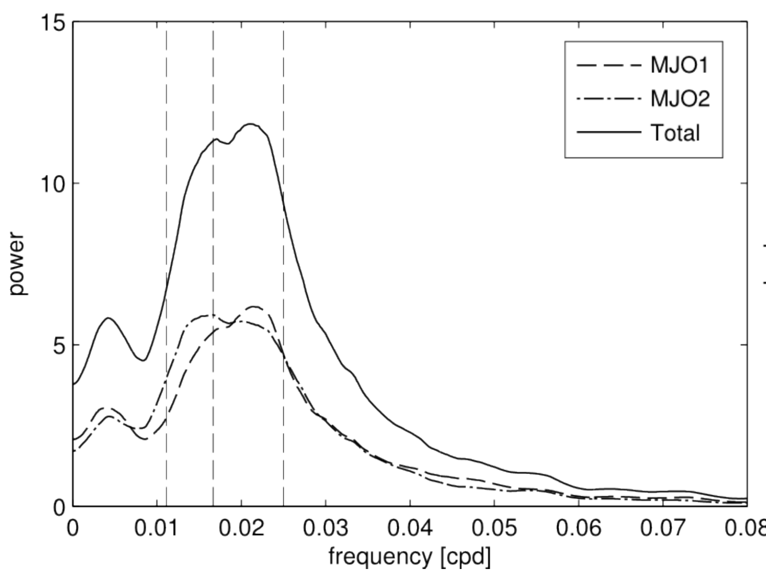

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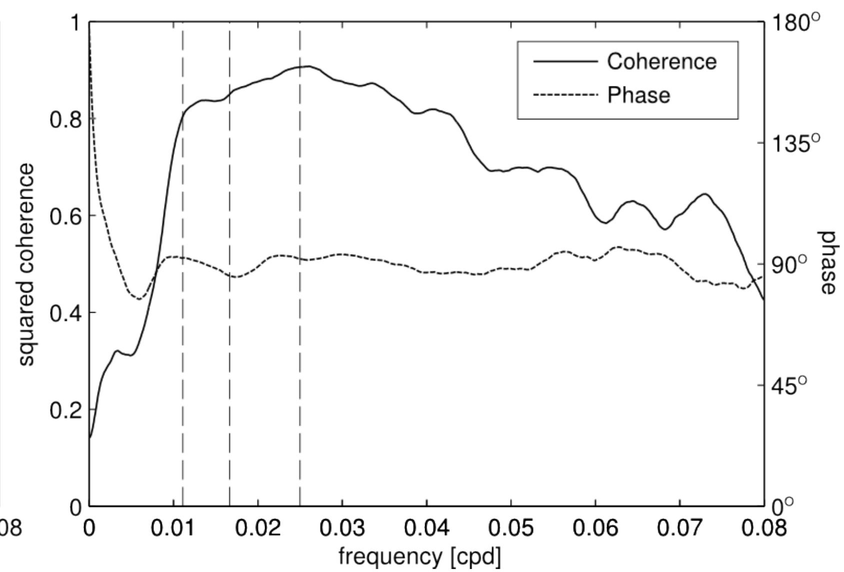
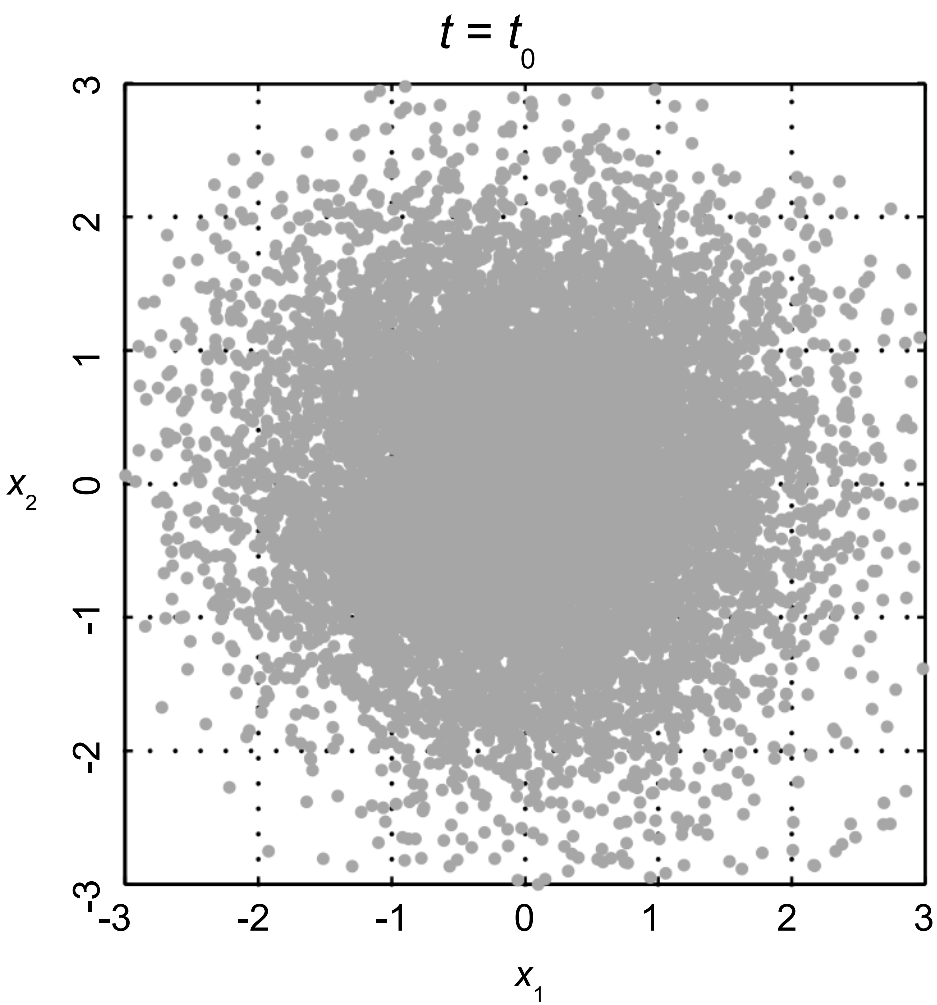


MJO Event Behaviour

- Distribution of all MJO index values distributed approx. as bivariate normal (grey)
- A subset is chosen (red, blue) with mean (dot) and 95% enclosure (circle)



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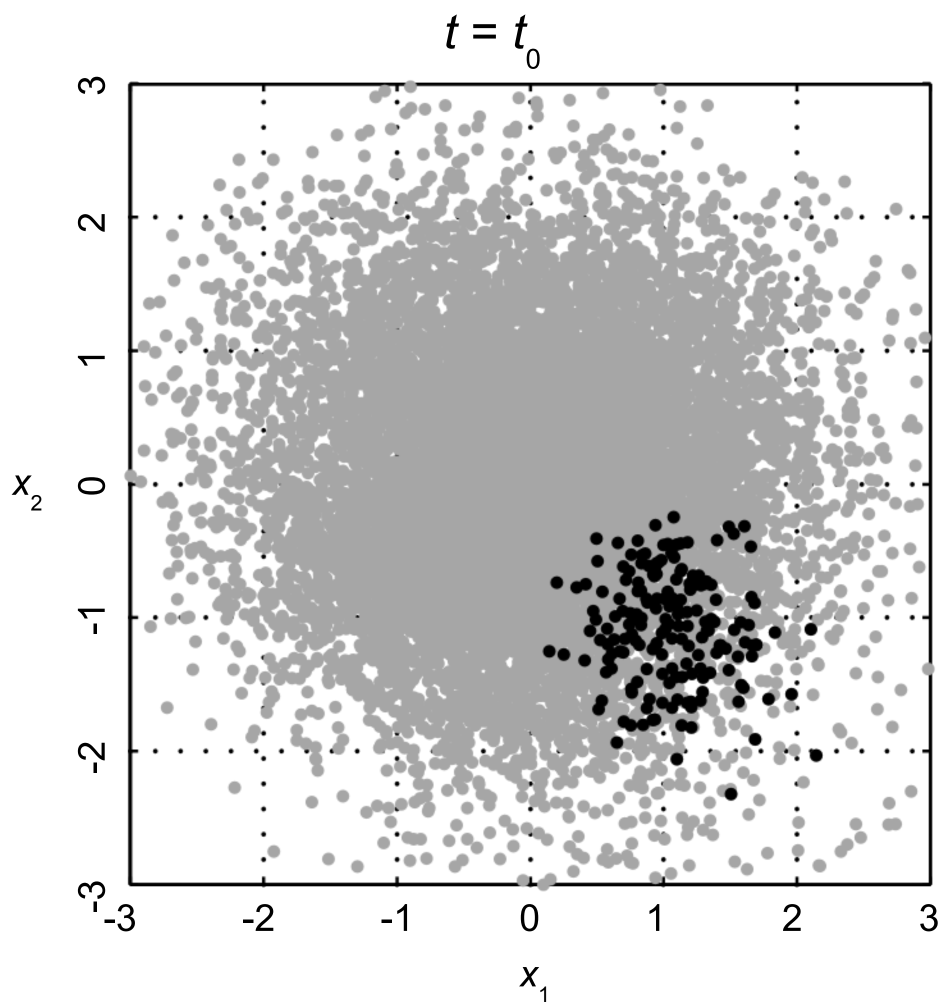

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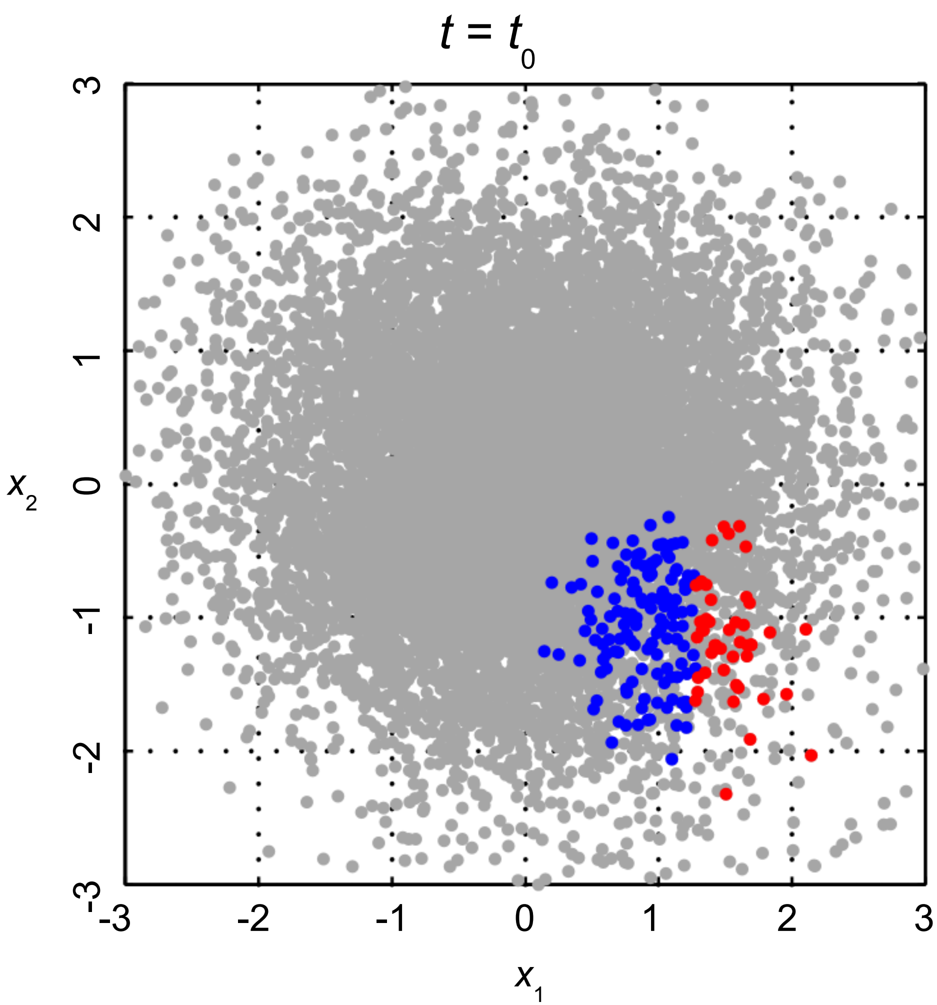

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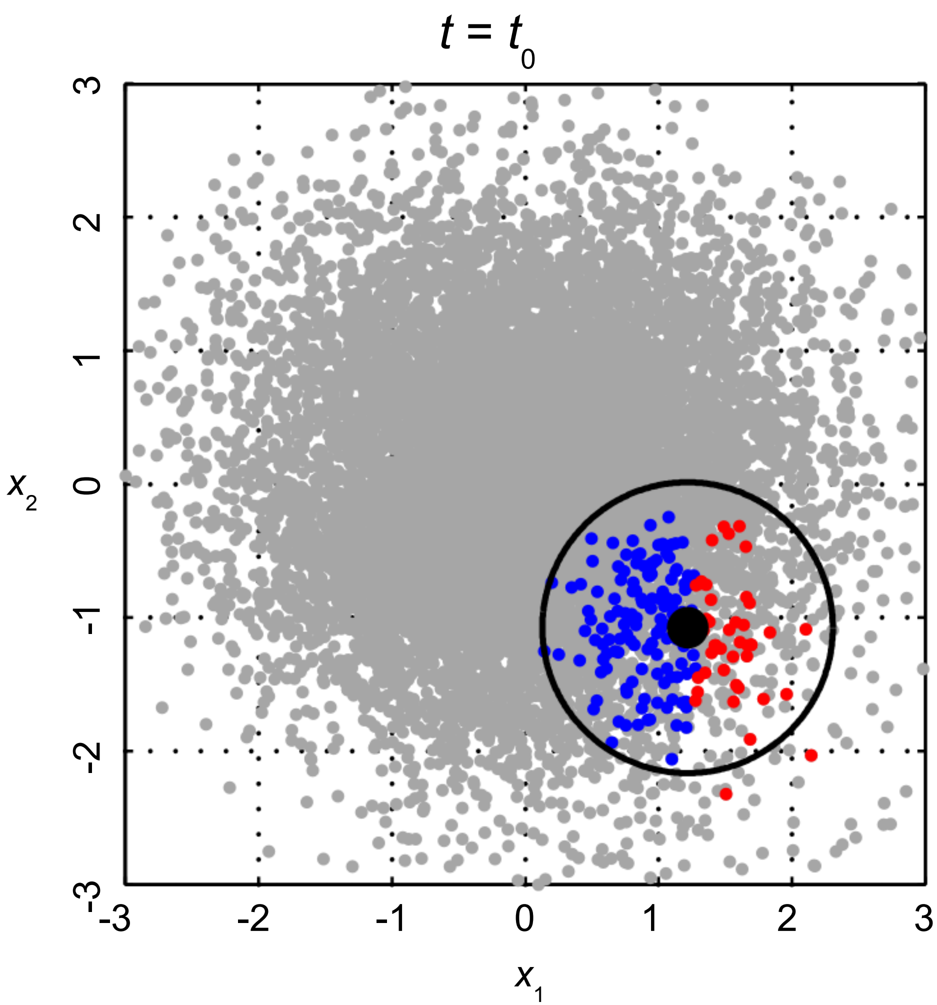

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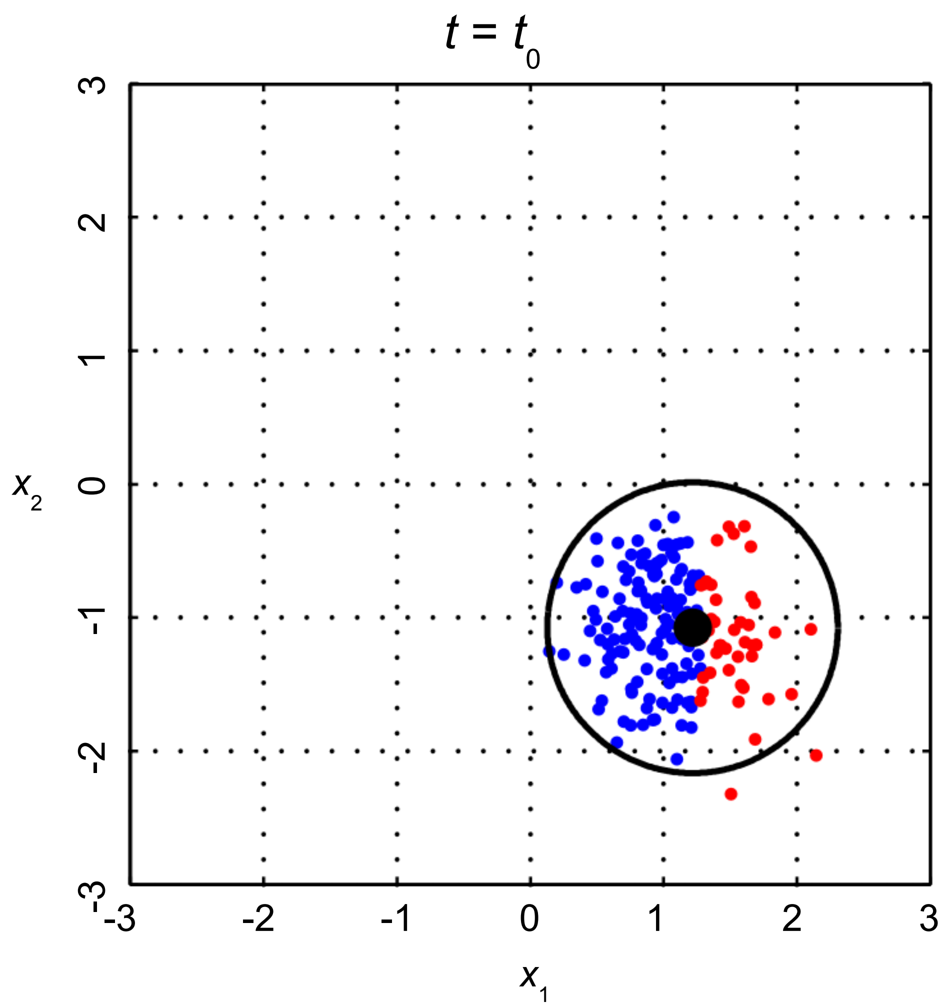

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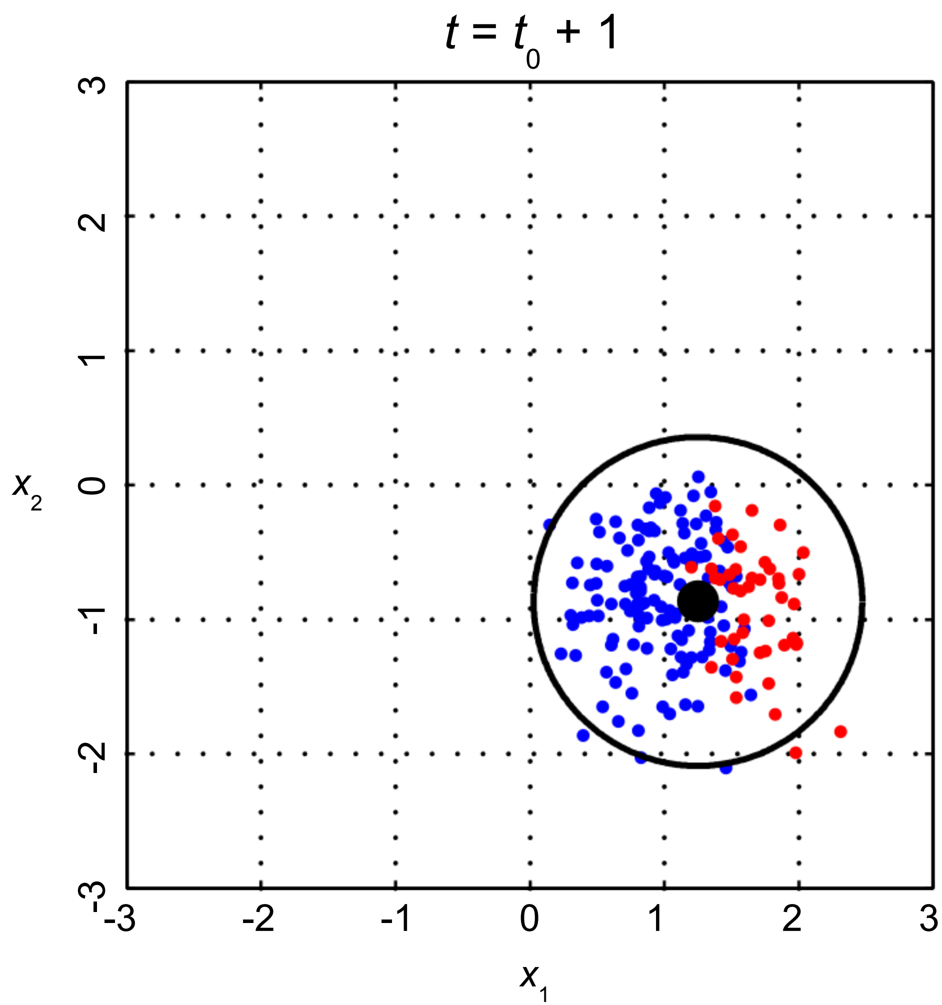

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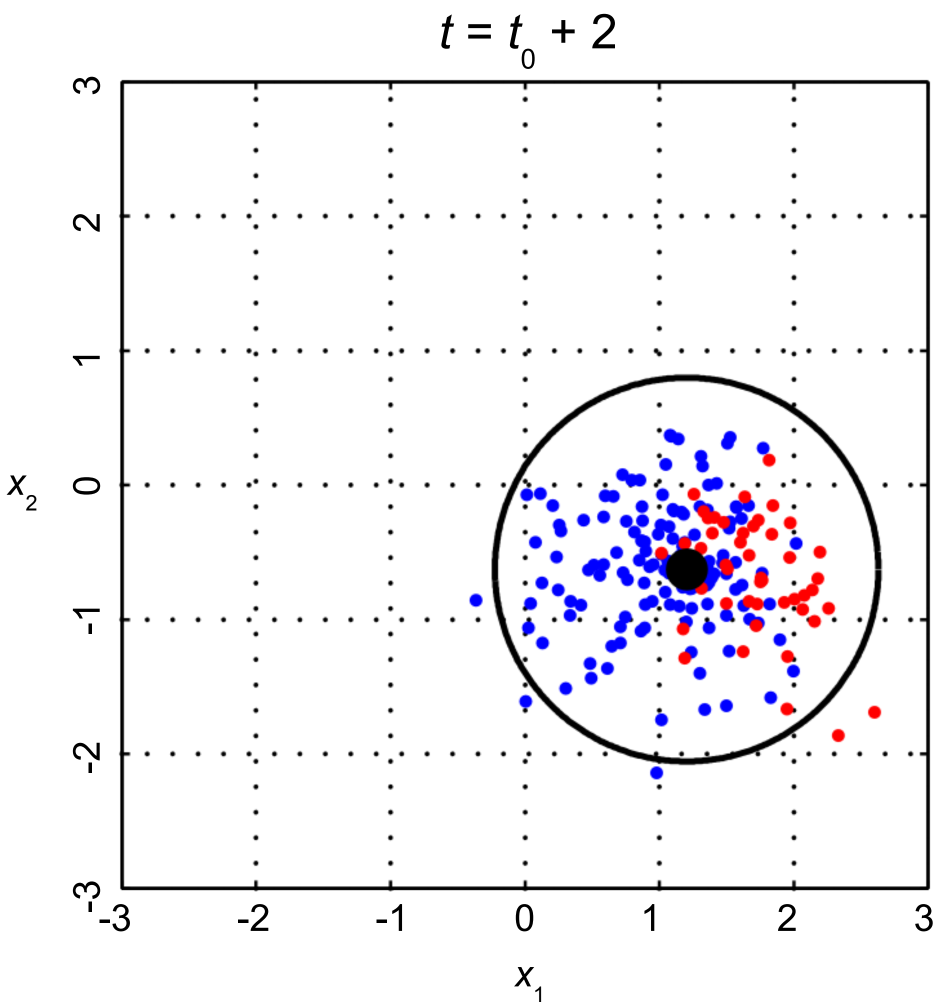

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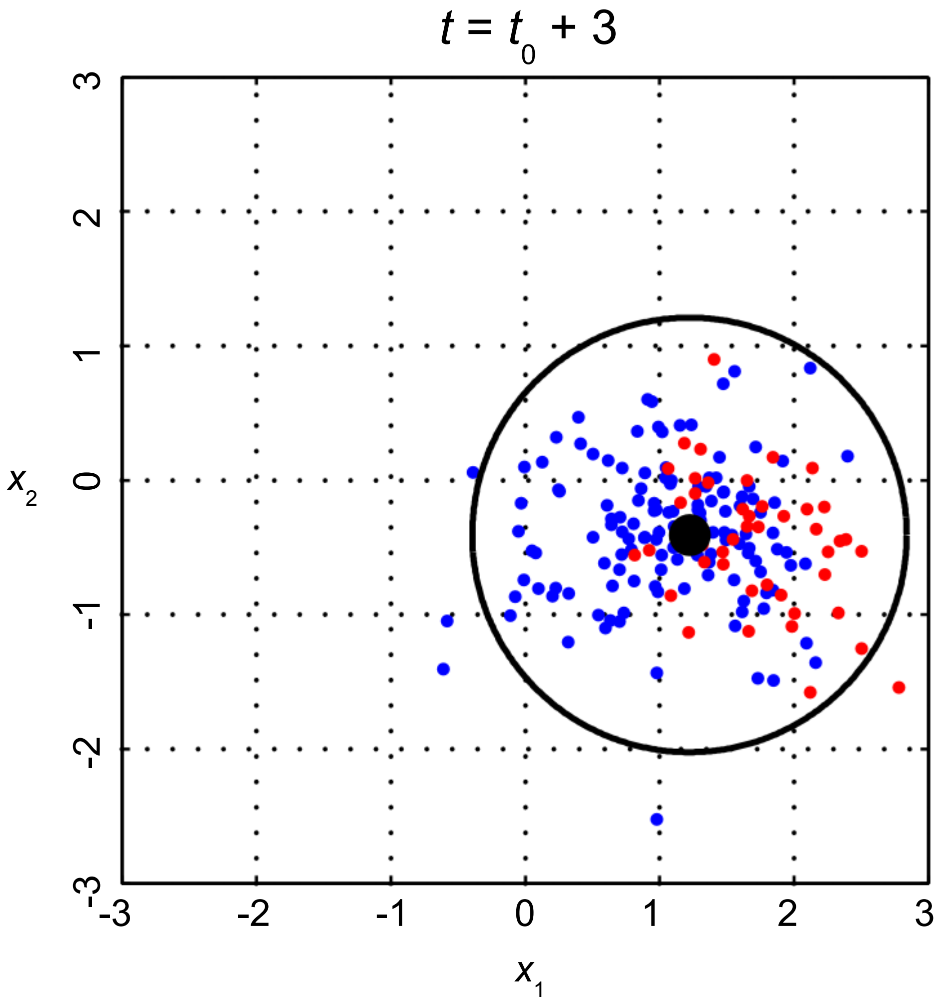

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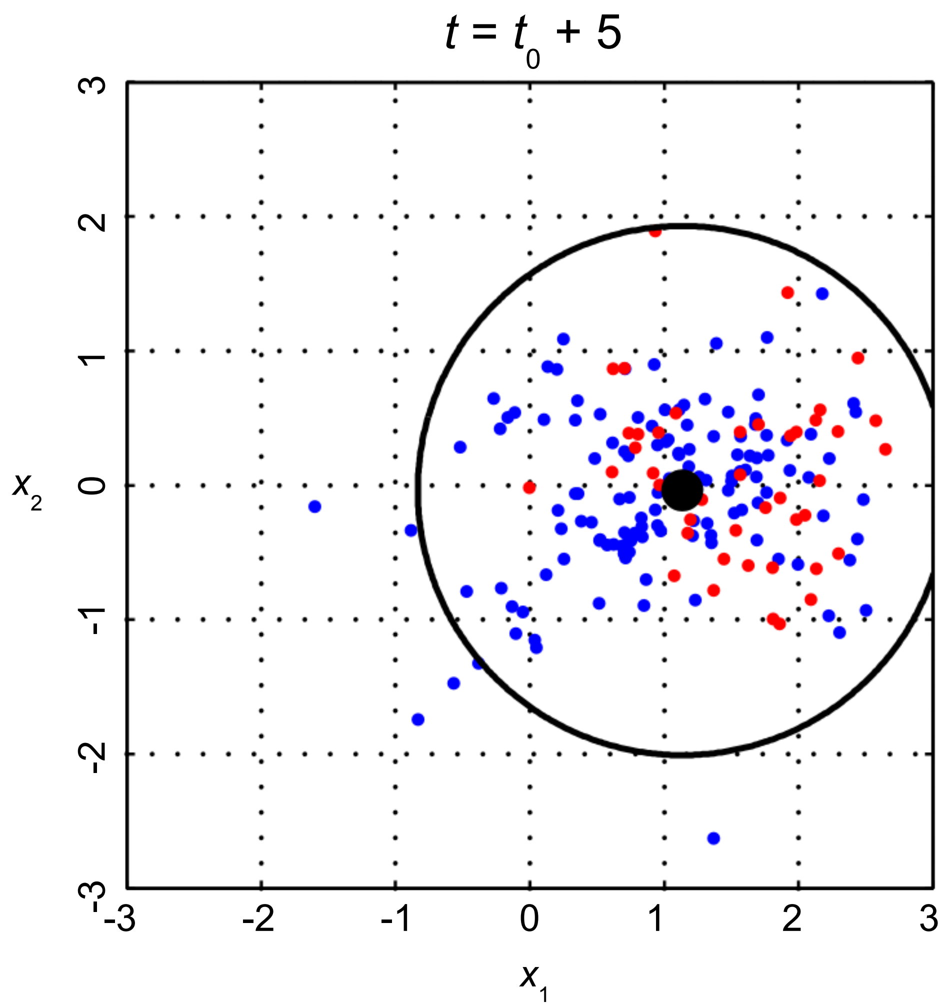

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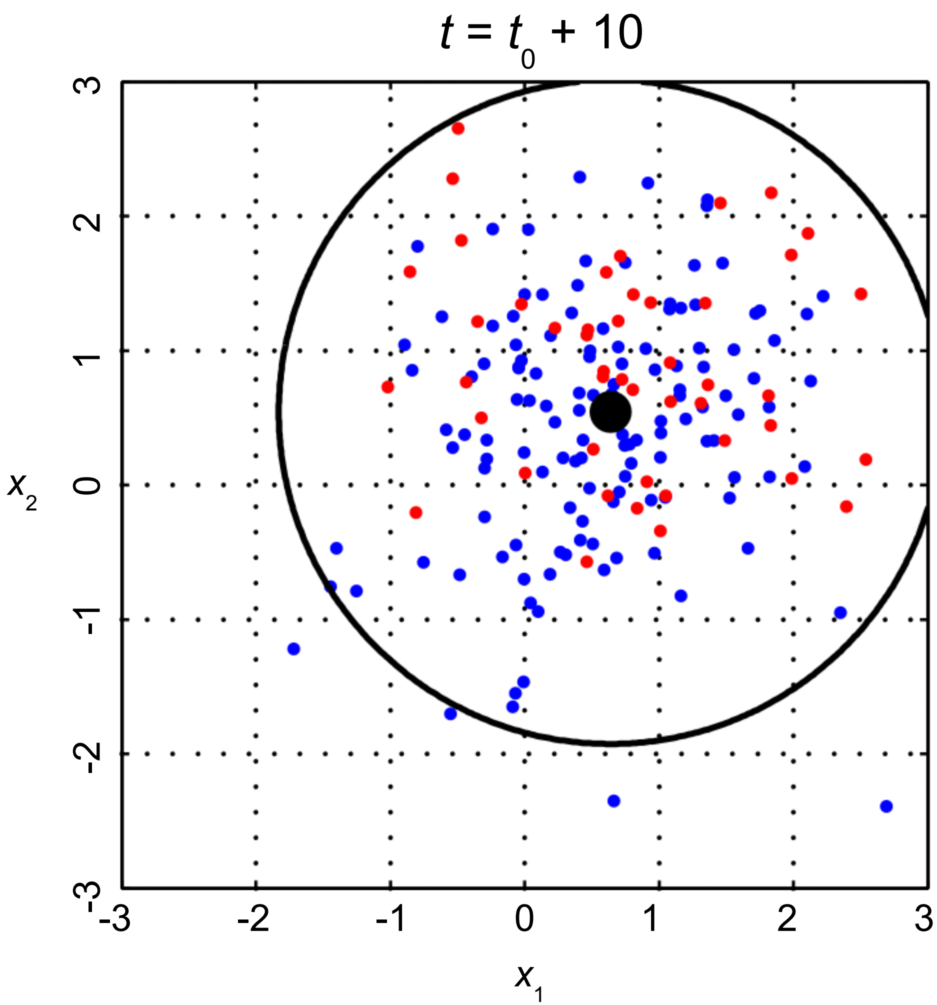

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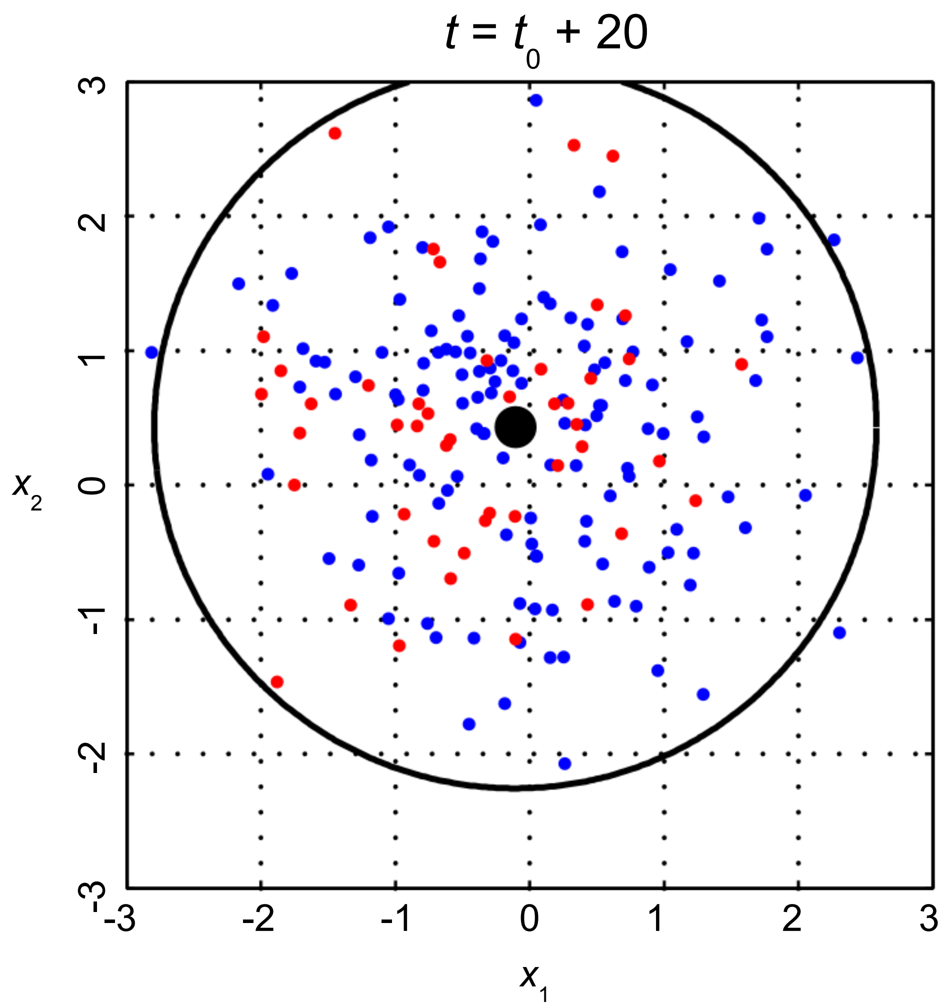

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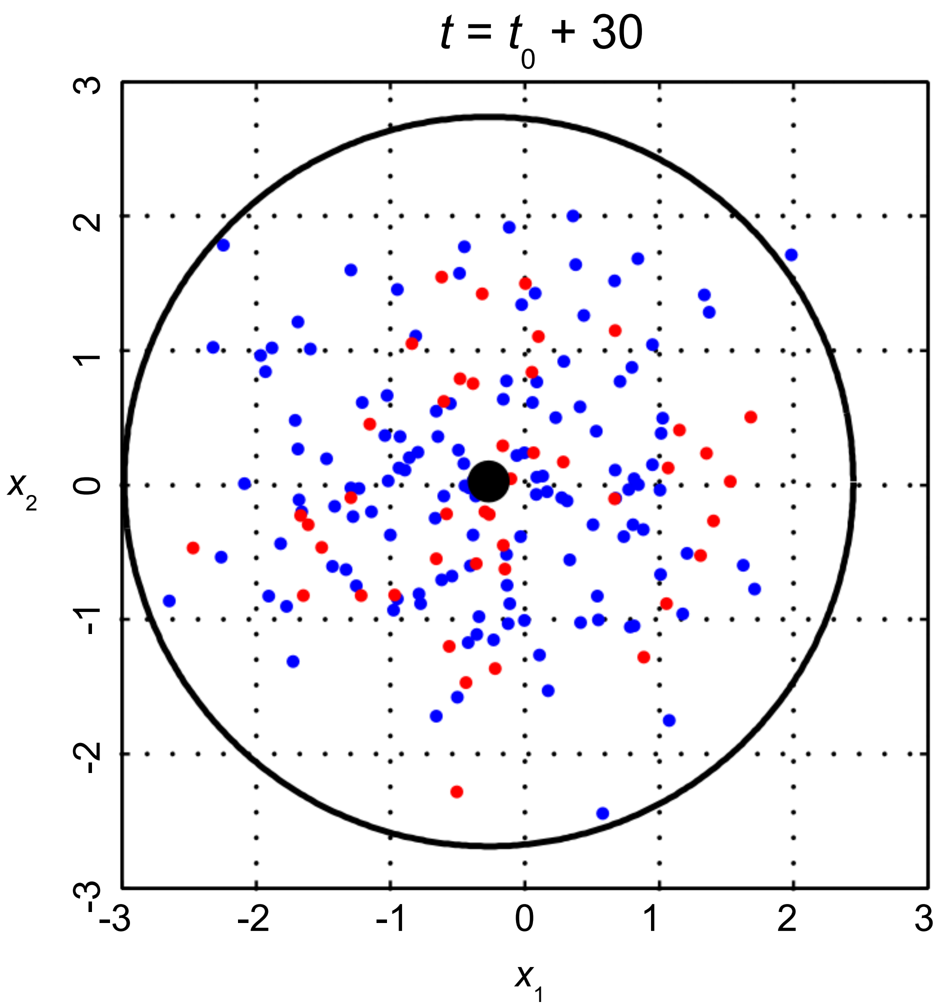
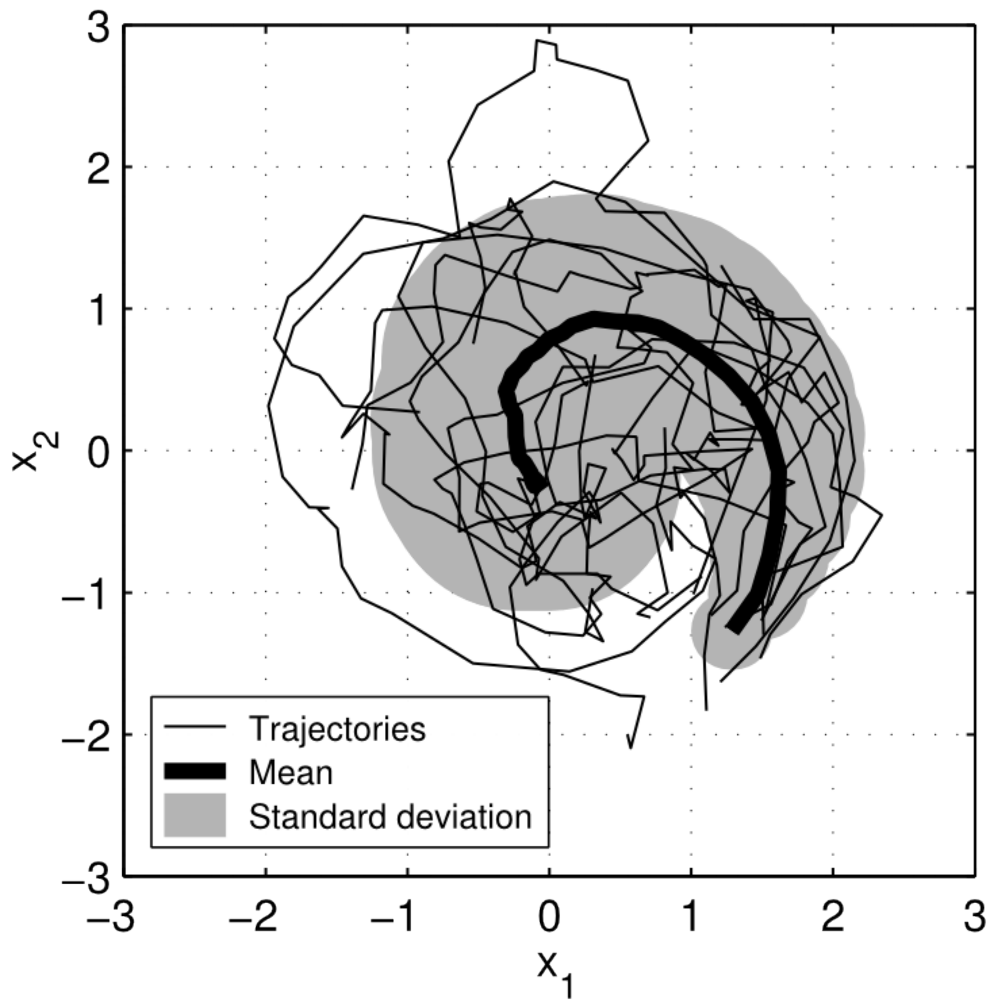


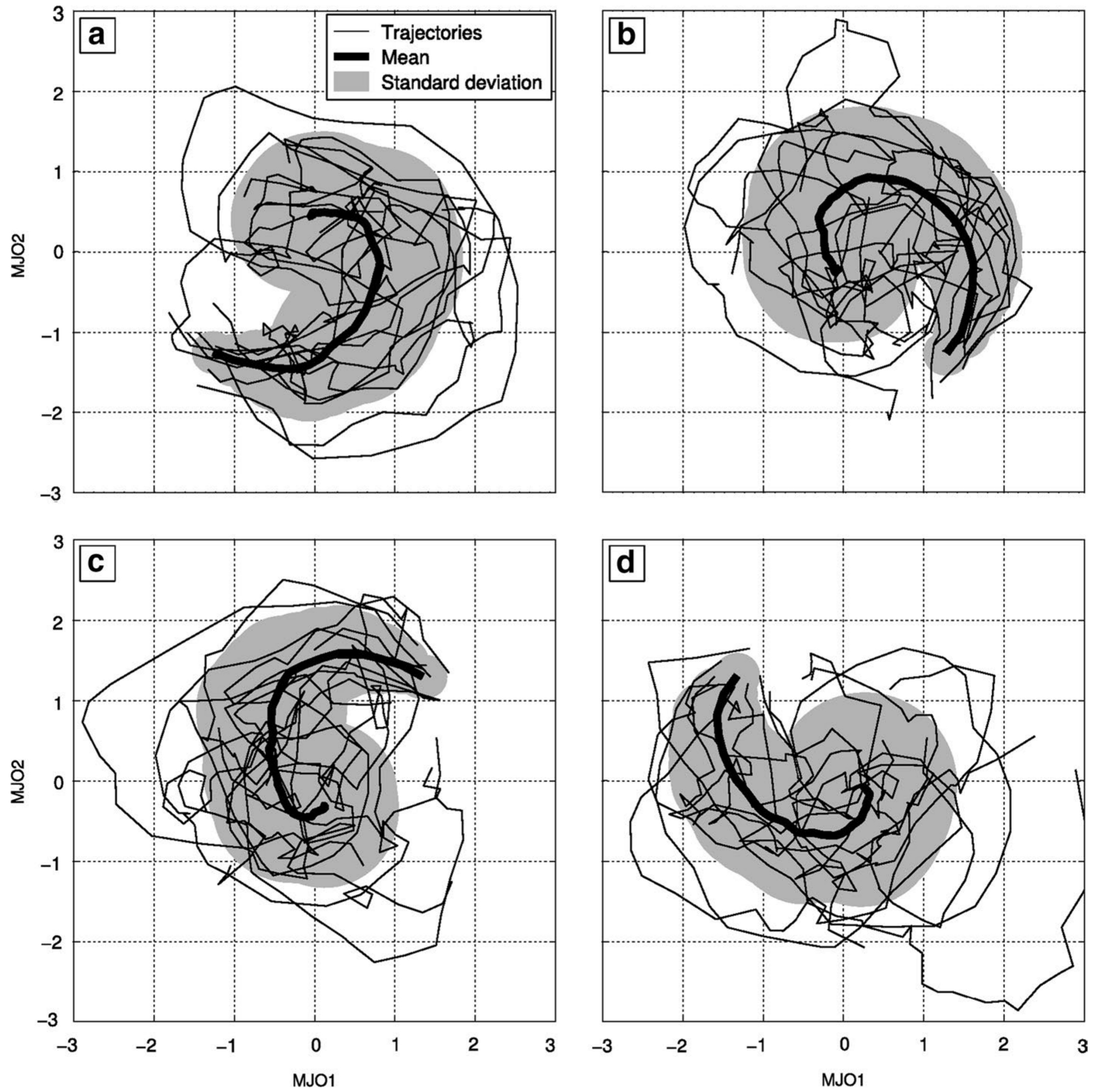
MJO Event Behaviour

- Distribution of all MJO index values distributed approx. as bivariate normal (grey)
- A subset is chosen (red, blue) with mean (dot) and 95% enclosure (circle)
- Time evolution shows spiralling of mean, increase of spread, and ensemble mixing



MJO Event Behaviour

- Similar patterns for initial conditions in other phases

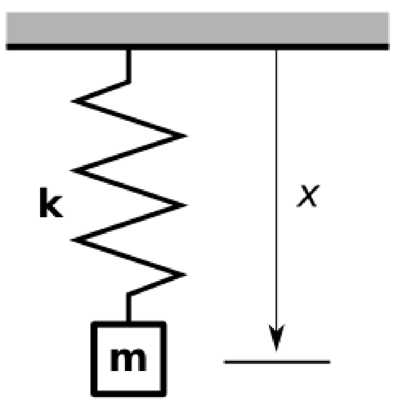


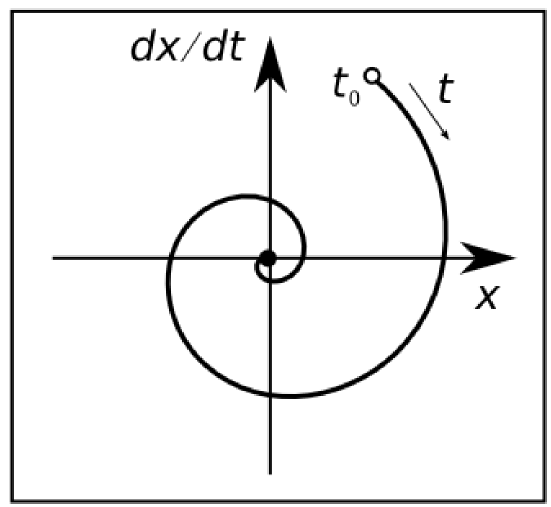
MJO Event Behaviour

- Distribution of all MJO index values distributed approx. as bivariate normal (grey)
- A
- T … g

Behaviour of a damped harmonic oscillator

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$$





Model

- A damped harmonic oscillator can be expressed as a **bivariate autoregressive** (1st-order; AR1) process:

$$\boldsymbol{x}_{t+1} = \boldsymbol{A}_1 \boldsymbol{x}_t + \boldsymbol{f}_{t+1} \qquad \boldsymbol{A}_1 = \gamma_1 \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

where $\boldsymbol{x} = [x_1 \ x_2]^T$ is the bivariate state vector, and $0 < \gamma_1 < 1$.

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- Forcing $\boldsymbol{f}_t$ is bivariate stochastic forcing (with memory)
  - AR1 with parameter $0 < \gamma_2 < 1$ (**Model 2**)

$$\boldsymbol{f}_{t+1} = \boldsymbol{A}_2 \boldsymbol{f}_t + \boldsymbol{\epsilon}_{t+1} \qquad \boldsymbol{A}_2 = \gamma_2 \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

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- Can re-express the whole system as a 4D AR1 process with $\boldsymbol{x} = [x_1 \; x_2 \; f_1 \; f_2]^T$ and can get expressions for <u>**mean ($\boldsymbol{\mu}$), covariance ($\boldsymbol{\Sigma}$), and correlation (ρ; mixing)**</u>

$$\boldsymbol{\mu}_{t_0+k} = \boldsymbol{A}^k \boldsymbol{\mu}_{t_0}$$

$$\boldsymbol{\Sigma}_{t_0+k,t_0} = \boldsymbol{A}^k \boldsymbol{\Sigma}_{t_0,t_0}$$

$$\rho_k^2 = \frac{\mathrm{tr}(\boldsymbol{\Sigma}_{t_0+k,t_0} \boldsymbol{\Sigma}_{t_0,t_0}^{-1} \boldsymbol{\Sigma}_{t_0,t_0+k})}{\mathrm{tr}(\boldsymbol{\Sigma}_{t_0+k,t_0+k})}$$

$$\boldsymbol{A} = \begin{bmatrix} \boldsymbol{A}_1 & \mathrm{I} \\ \boldsymbol{0} & \boldsymbol{A}_2 \end{bmatrix}$$

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Parameters (time scales)

$$P = 2\pi/\theta$$
$$\tau_1 = -1/\log\gamma_1$$
$$\tau_2 = -1/\log\gamma_2$$

- Can re-express the whole system as a 4D AR1 process with $\boldsymbol{x} = [x_1 \ x_2 \ f_1 \ f_2]^T$ and can get expressions for **mean (μ), covariance (Σ), and correlation (ρ; mixing)**

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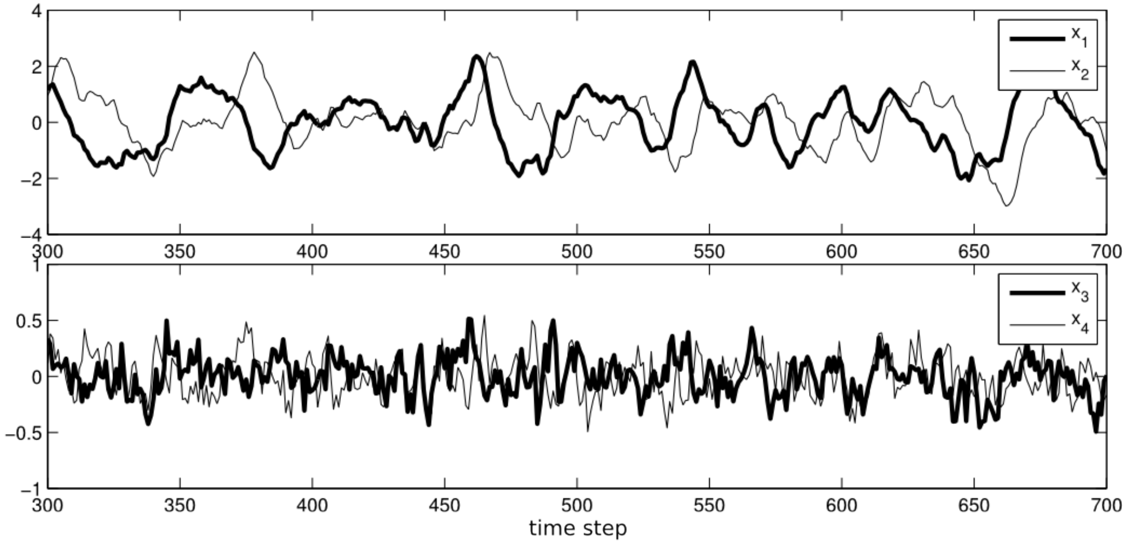
$$\boldsymbol{A} = \begin{bmatrix} \boldsymbol{A}_1 & \mathrm{I} \\ \boldsymbol{0} & \boldsymbol{A}_2 \end{bmatrix}$$

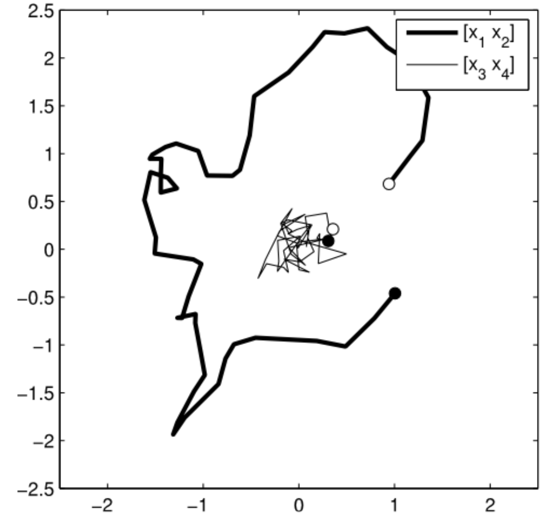
Model Behaviour

- Model behaviour with $P = 50$ days, $\tau_1 = 15$ days, $\tau_2 = 2$ days

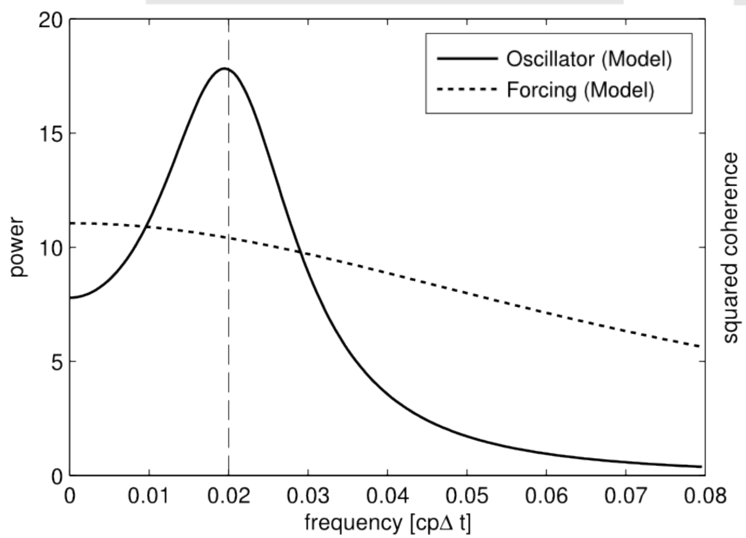
Oscillator model: Components 1 (—) and 2 (—)



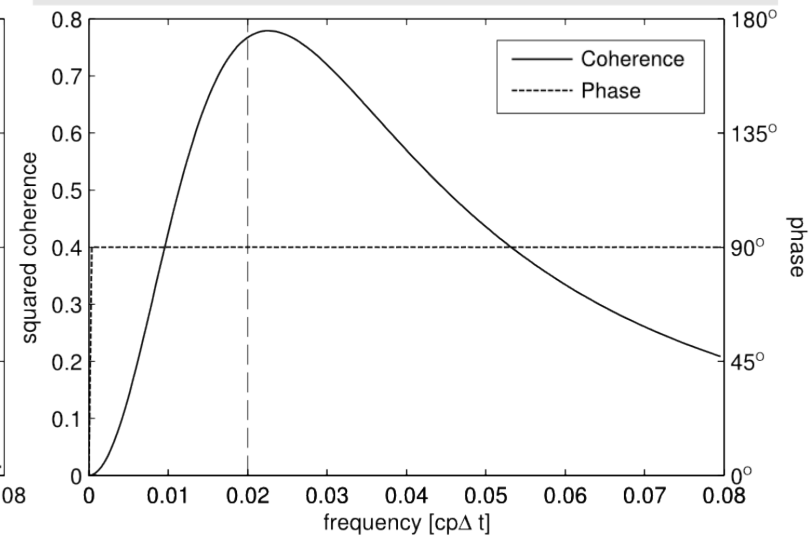
Phase Space



Oscillator power spectra

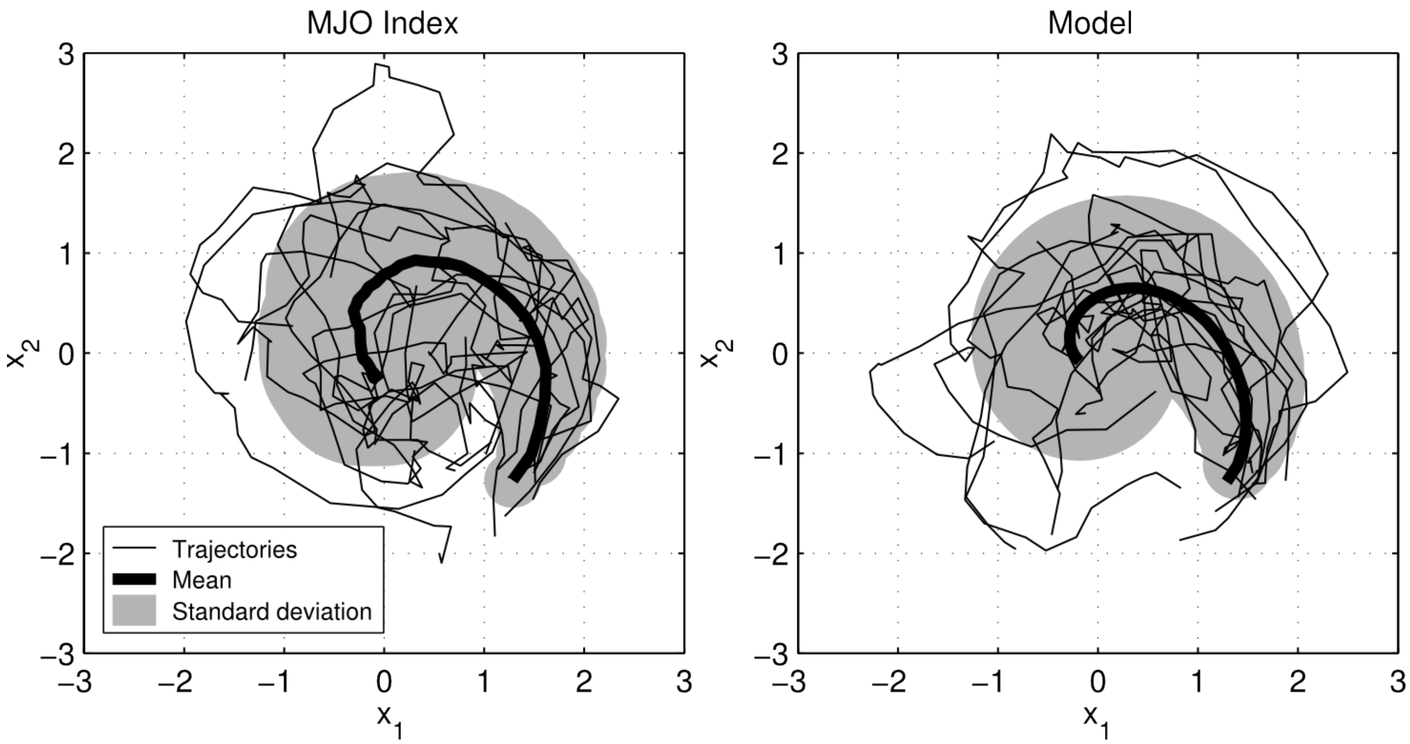


Oscillator coherence and phase spectra

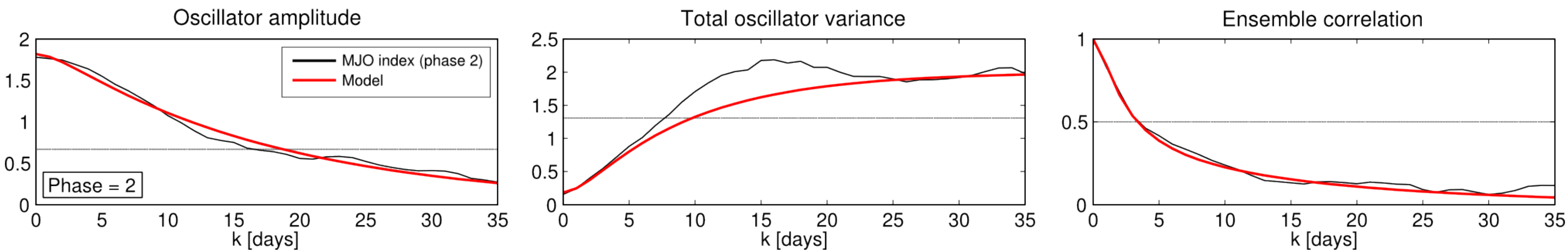


Model Behaviour

- Can use model to get ensemble statistics…



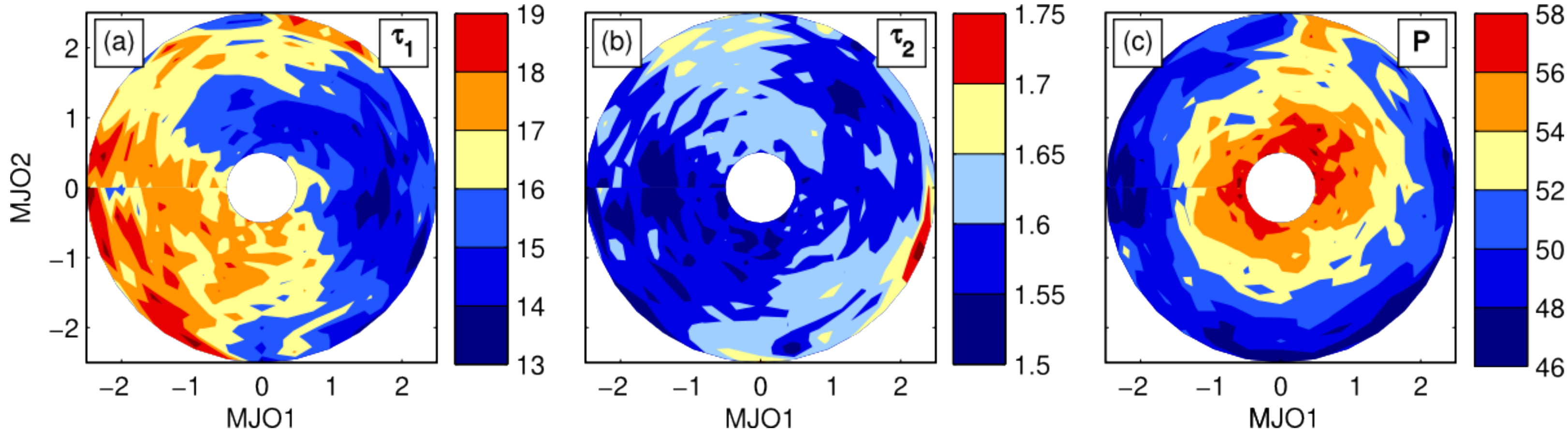
- …and three time scales (mean, variance, correlation)



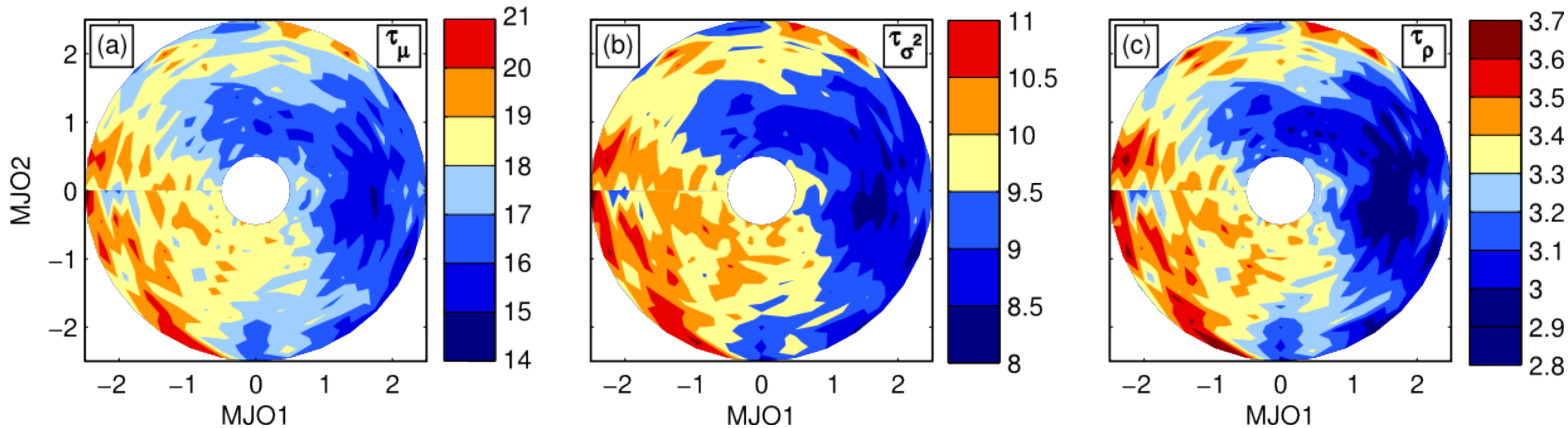
- Model can be fit (using max. likelihood estimation) to ensembles of trajectories

Model Fit

- Model fit for initial conditions covering most of phase space, to map out predictability
- Model parameters:



- Predictability time scales:



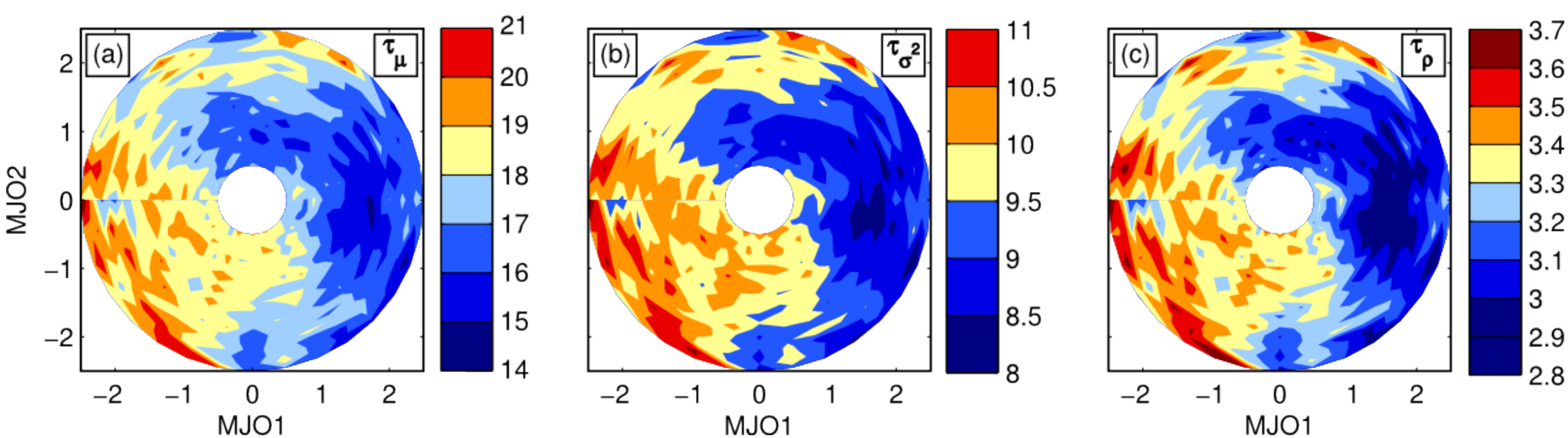
- Yin-Yang pattern: Strong dependency on initial condition

Phase dependency

- Model fit for initial conditions covering most of phase space, to map out predictability
- Model parameters:

- **Highest predictability** in phases 8, 1-2
  - Immediately before development of organized convection over Indian Ocean
- **Lowest predictability** in phases 4-5
  - Inherent Maritime Continent Predictability Barrier?

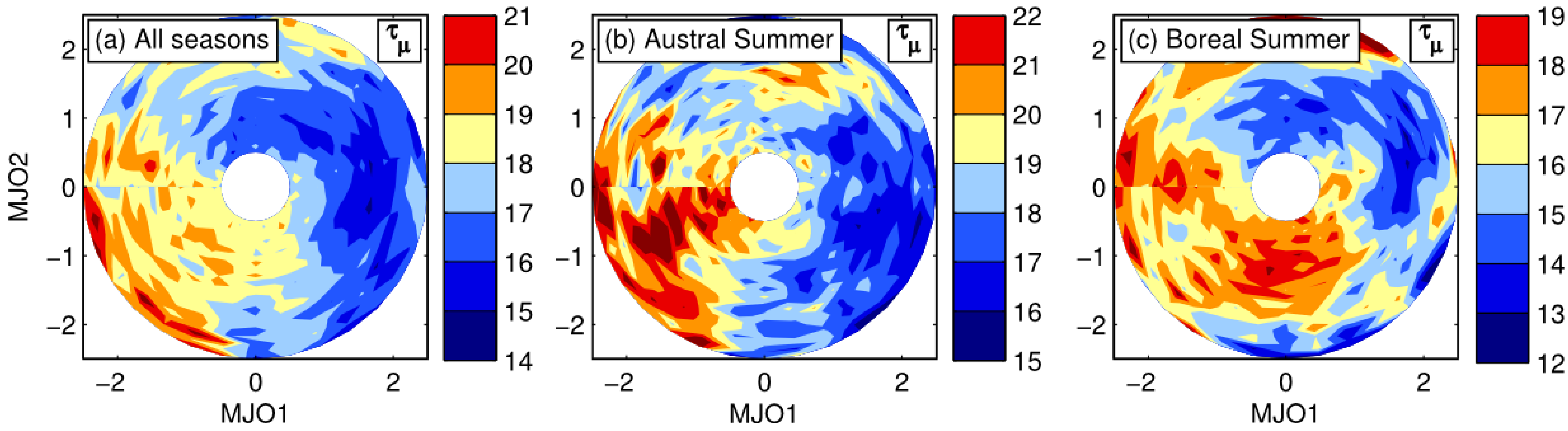
- Predictability time scales:



- Yin-Yang pattern: Strong dependency on initial condition

Seasonality

- Seasonality of predictability time scales



- **Highest** in Austral Summer (when MJO is strongest)
- Phase-timing of peak predictability **rotates** by ~1 phase with season!
- Note: MJO index does not measure *Boreal Summer Intraseasonal Oscillation*

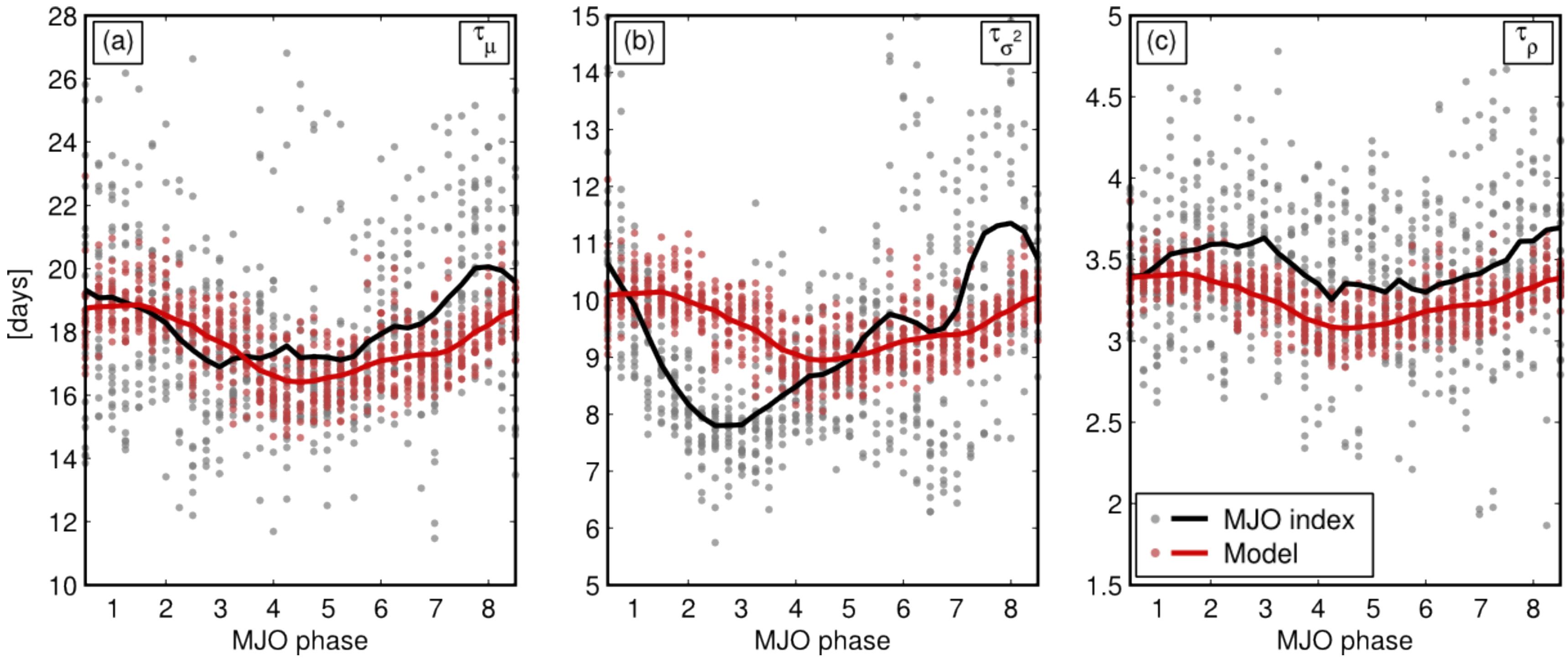
Summary

- MJO behaviour reminiscent of damped harmonic oscillator
- Simple model captures temporal and spectral properties of MJO as well as basic predictability
  - **2-3 week predictability for ensemble mean**
  - **~3 days for within ensemble correlation**
- MJO predictability varies with
  - Initial MJO phase
    - Highest in phases preceding MJO development over Indian Ocean
    - Lowest in phases initialized over Maritime Continent → Maritime Continent Prediction Barrier may be a property of the MJO itself and not a failing of numerical models
  - Season
    - Highest in Austral Summer (when MJO is strongest)

- **Publications**
  - Model first introduced: Oliver, E. C. J. and K. R. Thompson (2012), *A Reconstruction of Madden-Julian Oscillation Variability from 1905 to 2008*, **Journal of Climate**, 25(6)
  - More detail, including dependency on phase/season: Oliver, E. C. J. and K. R. Thompson (2015), *Predictability of the Madden Julian Oscillation index: Seasonality and dependence on MJO phase*, **Climate Dynamics** (online)

Phase dependency

- Phase dependency of predictability time scales



- **Highest predictability** in phases 8, 1-2
  - Immediately before development of organized convection over Indian Ocean
- **Lowest predictability** in phases 6-7
  - Inherent Maritime Continent Predictability Barrier?