Predicting extremes in the midlatitudinal atmospheric circulation using regime-dependent statistical modelling

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Outline

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Extreme events in complex systems

- deterministic or stochastic dynamics
- irregular
- endogeneous
- stationary dynamics
- no bifurcations or tipping points

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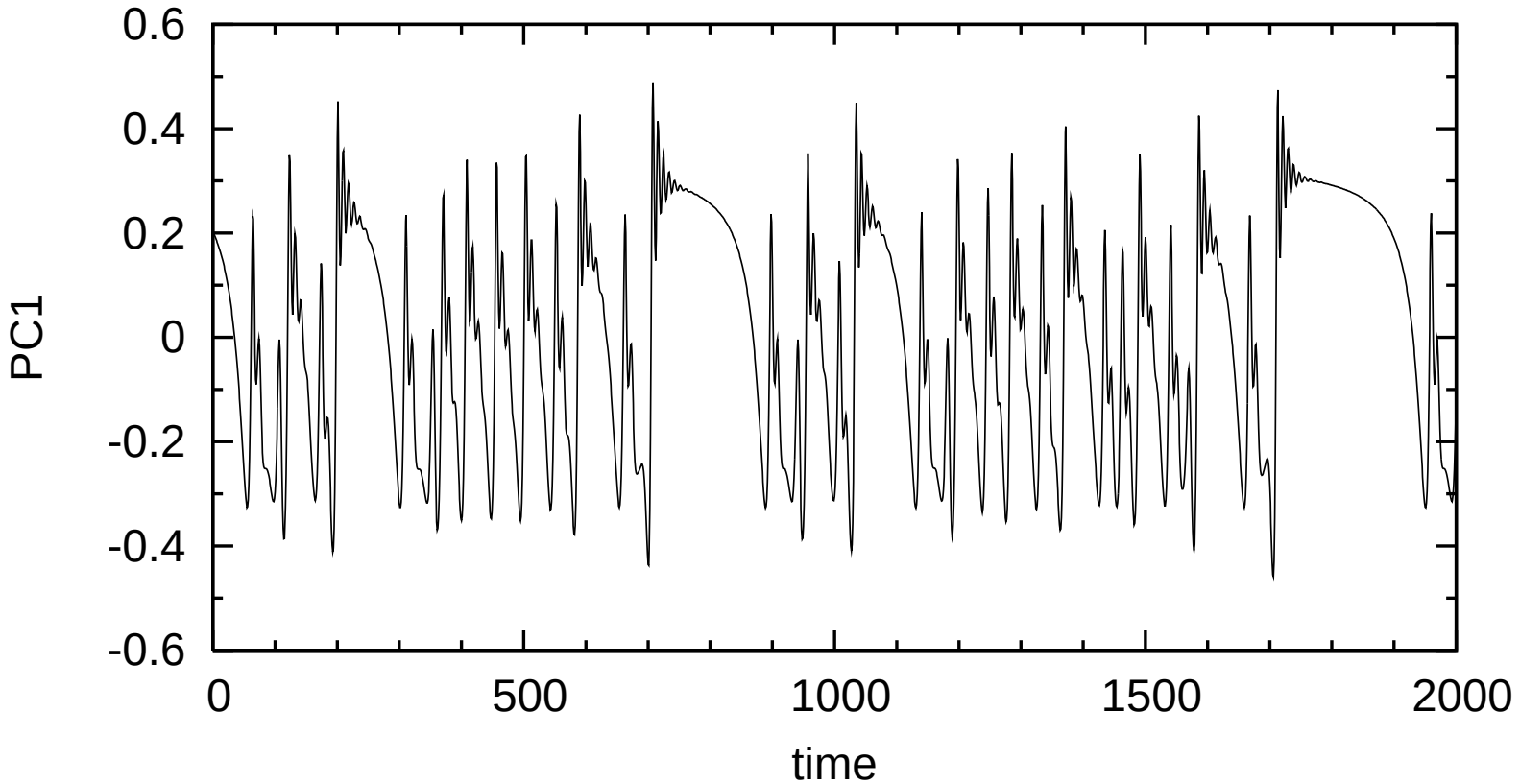
Atmospheric low-order model

Barotropic flow over topography in β-plane channel:

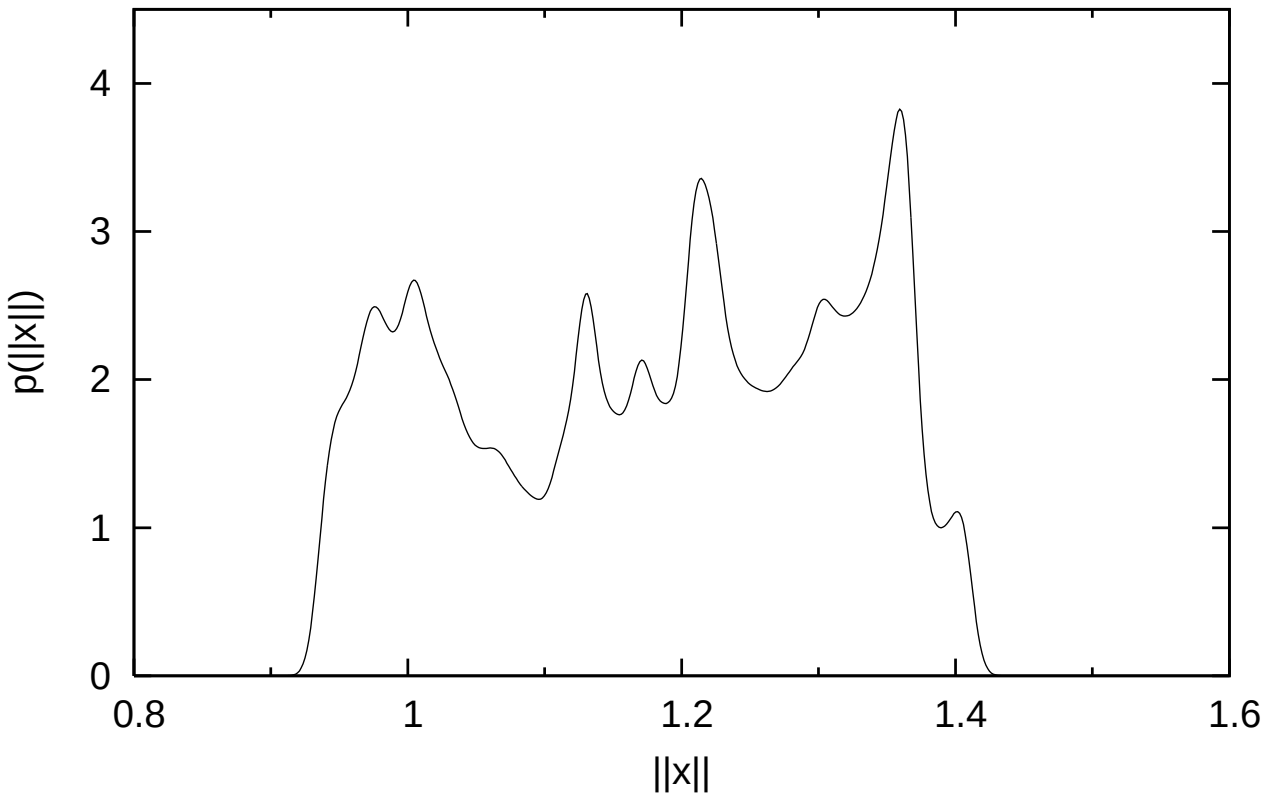
$$
\begin{aligned}
\dot{x}_1 &= \gamma_1^* x_3 - C(x_1 - x_1^*) \\
\dot{x}_2 &= -\alpha_1 x_1 x_3 + \beta_1 x_3 - C x_2 - \delta_1 x_4 x_6 \\
\dot{x}_3 &= \alpha_1 x_1 x_2 - \beta_1 x_2 - \gamma_1 x_1 - C x_3 + \delta_1 x_4 x_5 \\
\dot{x}_4 &= \gamma_2^* x_6 - C(x_4 - x_4^*) + \varepsilon(x_2 x_6 - x_3 x_5) \\
\dot{x}_5 &= -\alpha_2 x_1 x_6 + \beta_2 x_6 - C x_5 - \delta_2 x_3 x_4 \\
\dot{x}_6 &= \alpha_2 x_1 x_5 - \beta_2 x_5 - \gamma_2 x_4 - C x_6 + \delta_2 x_2 x_4
\end{aligned}
$$

Charney and DeVore 1979; DeSwart 1989; Crommelin et al. 2004

Time series of first PC



Extreme values of $||\mathbf{x}||$



Outline

Regime-dependent prediction model

Cluster-weighted modelling (*Gershenfeld et al. 1999*)

$$p(\mathbf{c}^0, e_\alpha^\tau) = \sum_{k=1}^{K} w_k \, p(\mathbf{c}^0|k) \, p(e_\alpha^\tau|\mathbf{y}^0, \mathbf{c}^0, k)$$

Predictive probability density:

$$p(e_\alpha^\tau|\mathbf{c}^0) = \sum_{k=1}^{K} g_k(\mathbf{c}^0) \, p(e_\alpha^\tau|\mathbf{c}^0, k) \qquad \text{with} \quad g_k(\mathbf{c}^0) = p(k|\mathbf{c}^0)$$

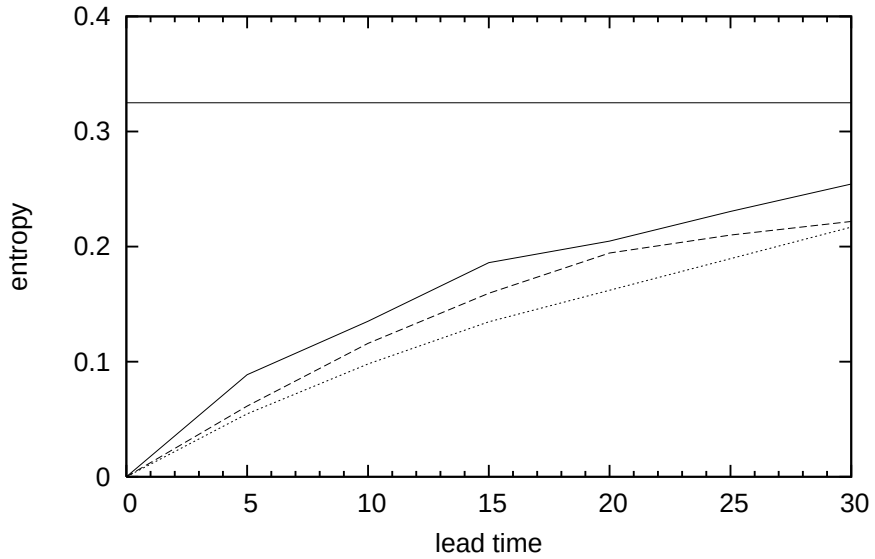
non-linear, non-Gaussian probabilistic modelling

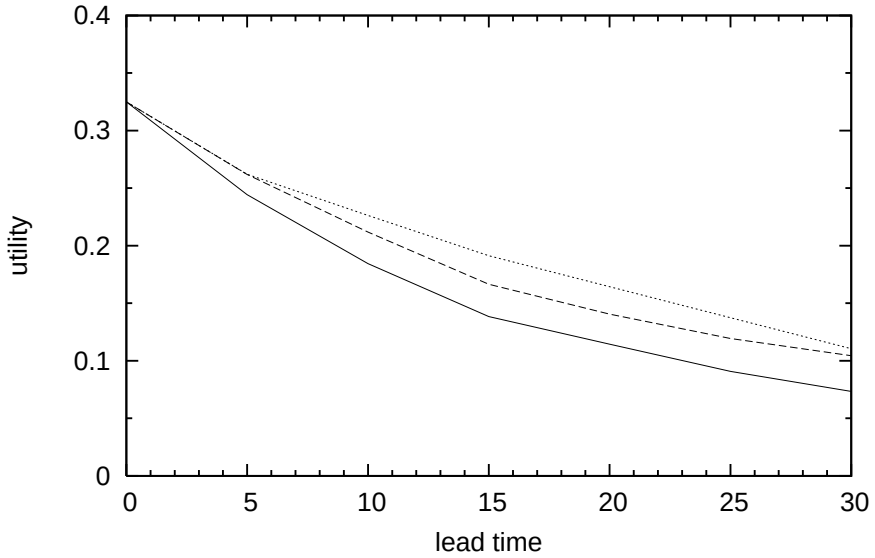
parameter estimation with expectation-maximisation (EM) algorithm

relating to precursor patterns

Outline

Information content of forecasts for $b = 0.1$





Probabilistic skill scores

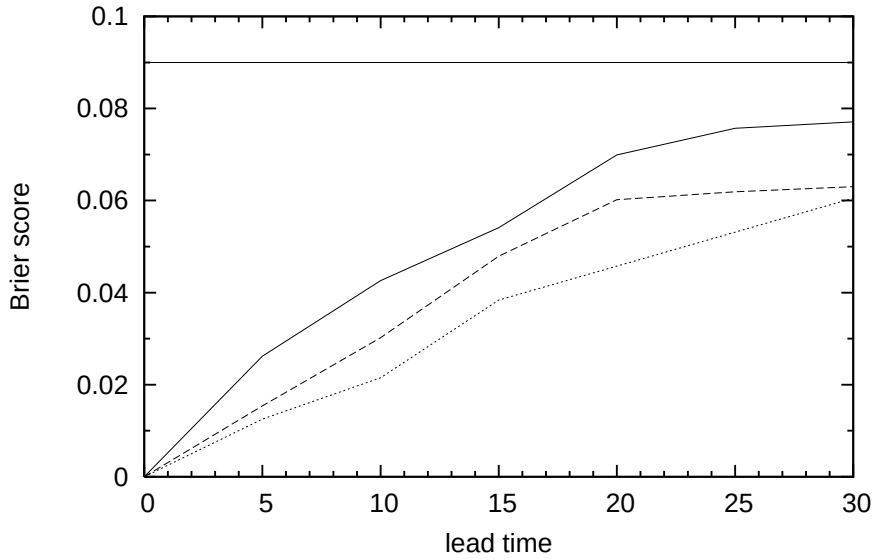
Brier score:

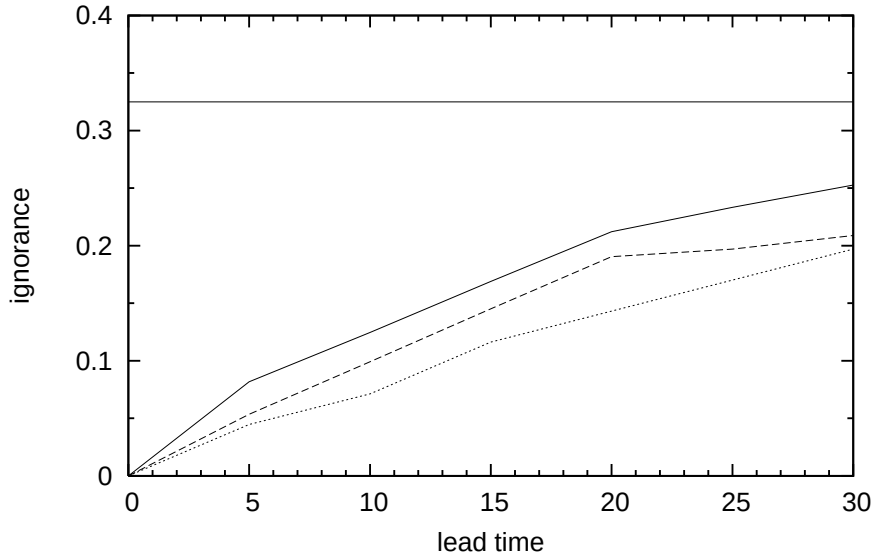
$$\mathrm{Br} = \sum_{\alpha} (f_\alpha - e_\alpha)^2$$

Ignorance score:

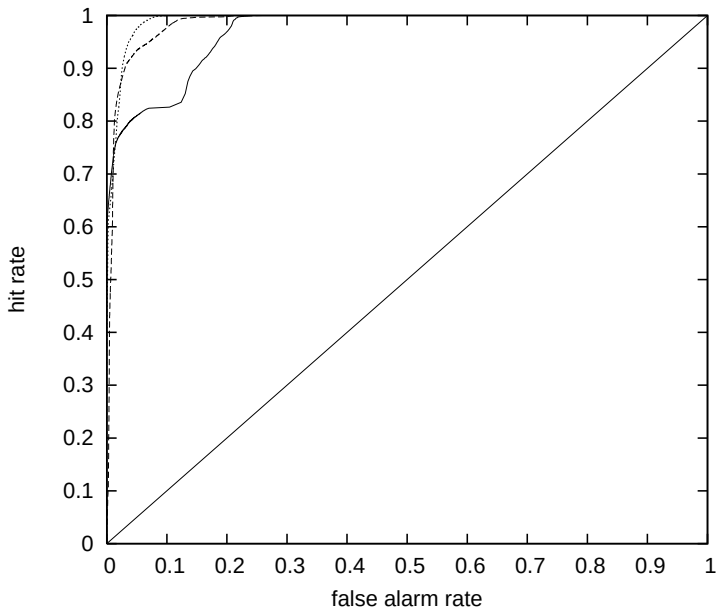
$$\mathrm{ign} = -\log f_\alpha$$

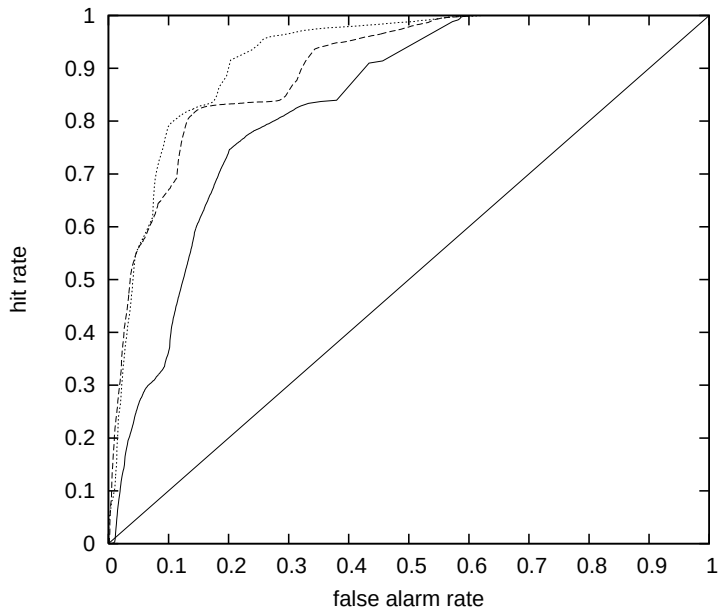
Forecast skill for $b = 0.1$





ROC curves for $b = 0.1$ and $\tau = 10, 30$





Model parameters

$b = 0.05$, $\tau = 25$, $K = 10$:

$w_1 = 0.124$, $\rho_1 = 0.340$
$w_2 = 0.073$, $\rho_2 = 0.038$
$w_3 = 0.082$, $\rho_3 = 0.021$
$w_4 = 0.104$, $\rho_4 = 0.018$
$w_5 = 0.078$, $\rho_5 = 0.010$
$w_6 = 0.126$, $\rho_6 = 0.003$
$w_7 = 0.158$, $\rho_7 = 0.000$
$w_8 = 0.103$, $\rho_8 = 0.000$
$w_9 = 0.081$, $\rho_9 = 0.000$
$w_{10} = 0.072$, $\rho_{10} = 0.000$

ROC curves for different event rarity; $\tau = 30$, $K = 15$