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

Frank Kwasniok

Exeter Climate Systems (XCS),
College of Engineering, Mathematics and Physical Sciences,
University of Exeter, Exeter, UK

Isaac Newton Institute, Cambridge, 20 October 2010

Outline

Outline

Extreme events in complex systems

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

Outline

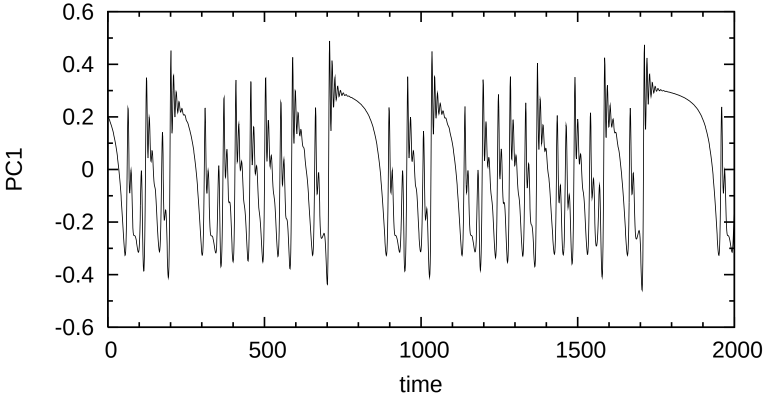
Atmospheric low-order model

Barotropic flow over topography in β-plane channel:

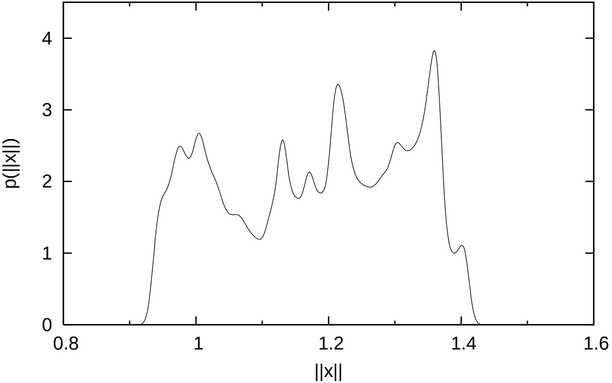
$$
\begin{aligned}
\dot{x}_1 &= \gamma_1^* x_3 - C(x_1 - x_1^*) \\
\dot{x}_2 &= -\alpha_1 x_1 x_3 + \beta_1 x_3 - C x_2 - \delta_1 x_4 x_6 \\
\dot{x}_3 &= \alpha_1 x_1 x_2 - \beta_1 x_2 - \gamma_1 x_1 - C x_3 + \delta_1 x_4 x_5 \\
\dot{x}_4 &= \gamma_2^* x_6 - C(x_4 - x_4^*) + \varepsilon(x_2 x_6 - x_3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

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:

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

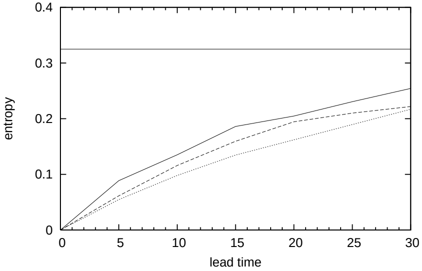
non-linear, non-Gaussian probabilistic modelling

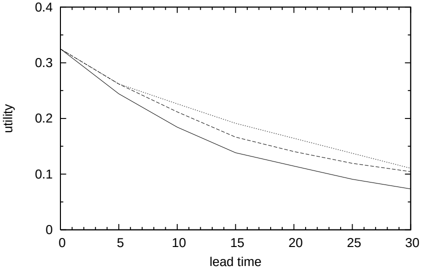
parameter estimation with expectation-maximisation (EM) algorithm

relating to precursor patterns

Outline

Information content of forecasts for $b = 0.1$





Probabilistic skill scores

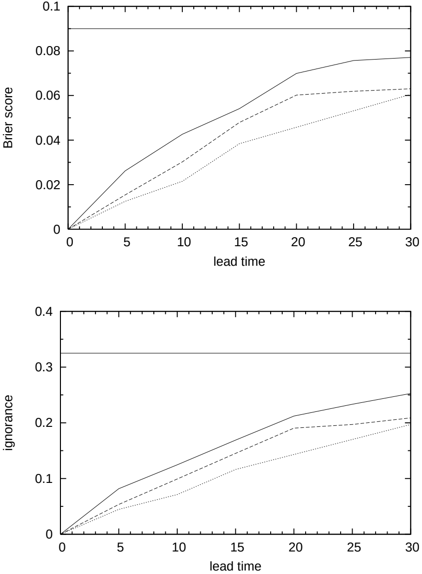
Brier score:

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

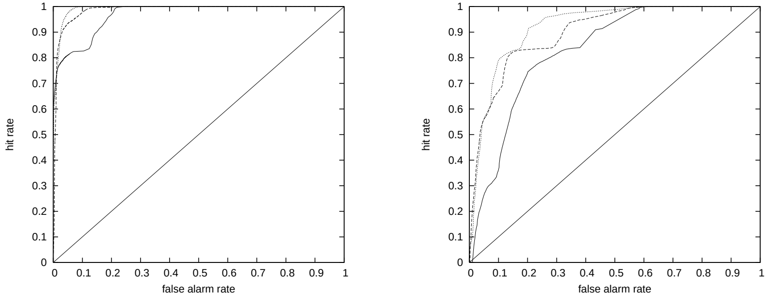
Ignorance score:

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

Forecast skill for $b = 0.1$



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



Model parameters

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

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

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