Spatio-temporal Gaussian process to detect outbreaks of pests: a case study from the Great Barrier Reef

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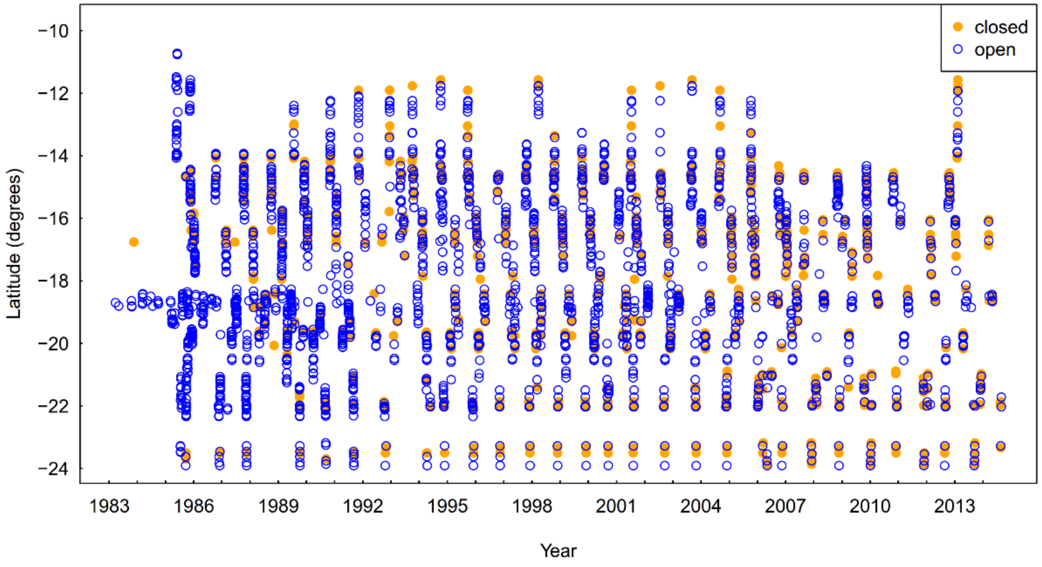
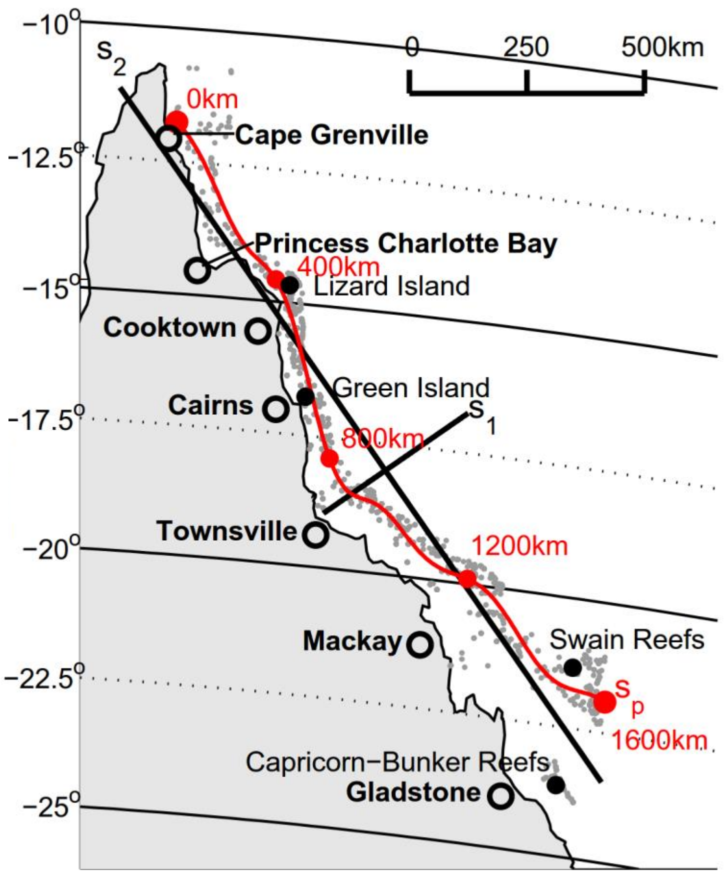
Spatio-temporal fluctuations of Crown of thorns star fish (COTS) in the Great Barrier Reef

- COTS are native species at GBR
  - They eat coral
  - Their life history supports boom and bust behavior
  - During outbreaks cause coral depletion
- In recent decades their abundance has increased and outbreaks have become more severe
  - Currently, the number one reason for coral depletion
- Aims
  - Visualize the outbreaks
  - Support hypotheses on reasons of COTS dynamics
  - Redefine the operational definition of an outbreak

Study area: the Great Barrier Reef (GBR)

Data and study area





Spatio-temporal abundance model

$$y_i \sim \text{Negative}-\text{Binomial}\left(e_i \lambda(x_i, s_i, t_i), r\right)$$

$$\log \lambda(x_i, s_i, t_i) = \alpha + x_{i,\text{inner}} \beta_{i,\text{inner}} + x_{i,\text{outer}} \beta_{i,\text{outer}}$$
$$+ f_{\text{closure}}(\tau_{i,\text{pre04}}, \tau_{i,04}) + \phi(s_i) + g(s_i, t_i)$$

- Intercept, mid-shelf abundance level: $\alpha \sim N(0, \sigma_\alpha^2)$
- Effect of inner shelf reef: $\beta_{i,\text{inner}} \sim N\left(0, \sigma_\beta^2\right)$
- Effect of inner shelf reef: $\beta_{i,\text{outer}} \sim N\left(0, \sigma_\beta^2\right)$

Model: effect of fishing closure

$$\log \lambda(x_i, s_i, t_i) = \alpha + x_{i,\text{inner}}\beta_{i,\text{inner}} + x_{i,\text{outer}}\beta_{i,\text{outer}}$$
$$+ f_{\text{closure}}(\tau_{i,\text{pre04}}, \tau_{i,04}) + \phi(s_i) + g(s_i, t_i)$$

- $f_{\text{closure}} = \frac{\beta_{04}\tau_{i,04}}{a_{04}+\tau_{i,04}} + \frac{\beta_{\text{pre04}}\tau_{i,\text{pre04}}}{a_{\text{pre04}}+\tau_{i,\text{pre04}}}$
  - Michaelis-Menten response on time since
    - fishing closure before 2004: $\tau_{i,\text{pre04}}$
    - fishing closure in 2004: $\tau_{i,04}$

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Model: spatial and spatio-temporal random effects

$$\log \lambda(x_i, s_i, t_i) = \alpha + x_{i,\text{inner}}\beta_{i,\text{inner}} + x_{i,\text{outer}}\beta_{i,\text{outer}} + f_{\text{closure}}(\tau_{i,\text{pre04}}, \tau_{i,04}) + \phi(s_i) + g(s_i, t_i)$$

- $\phi(s_i)$ spatial random effect: stable hot-spots
  - Gaussian process with exponential covariance function

$$\text{Cov}\left(\phi(s_i), \phi(s_j)\right) = \sigma_1^2 e^{-||s_i - s_j||/l_1}$$

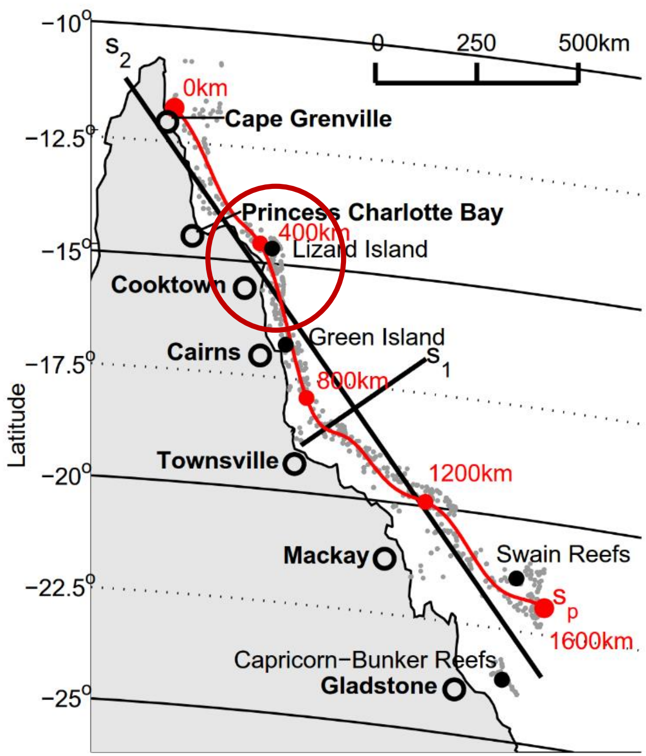
- $g(s_i, t_i)$ spatio-temporal random effect: Dynamic changes in COTS abundance (outbreaks)
  - Gaussian process with separable covariance function

$$\text{Cov}\left(g(s_i, t_i), g(s_j, t_j)\right) = \sigma_2^2 e^{-||s_i - s_j||/l_2} e^{-||t_i - t_j||/l_3}$$

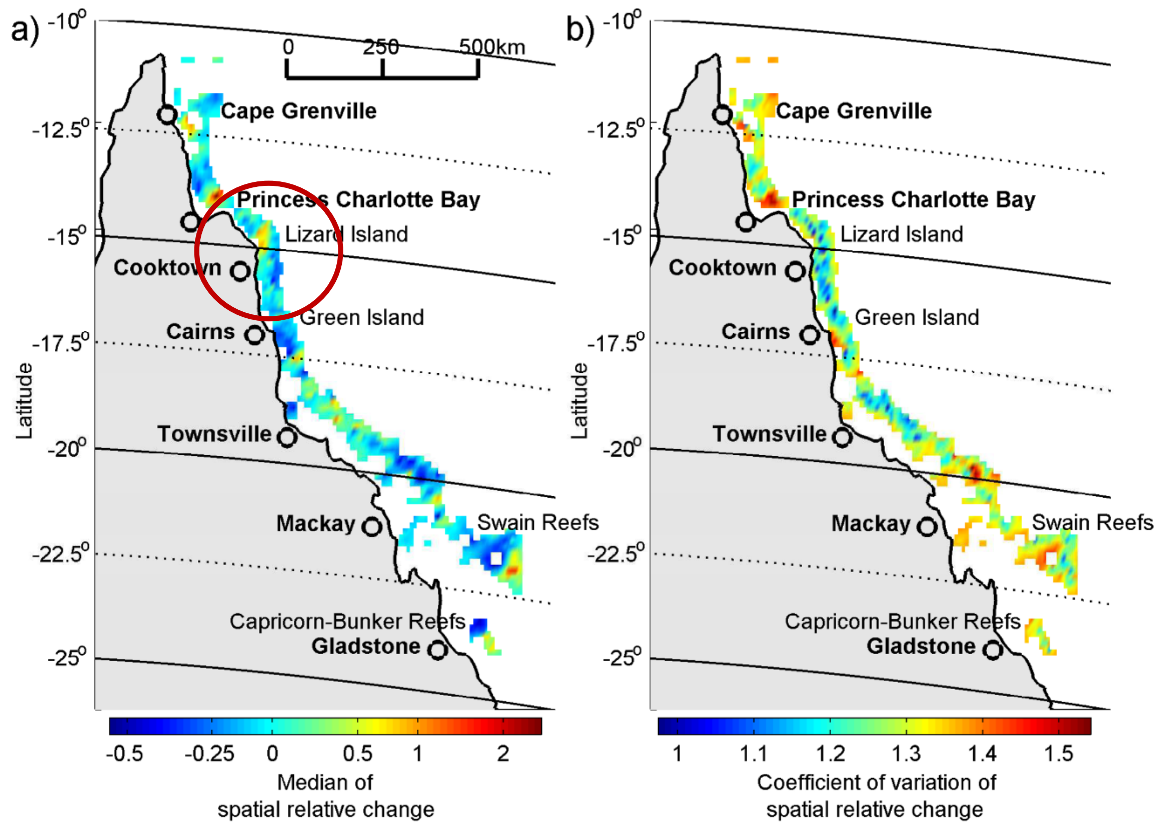
Spatial relative change in intensity:

$$\frac{e^{f(x,s,t)} - e^{f(x,s,t)-\phi(s)}}{e^{f(x,s,t)-\phi(s)}} = e^{\phi(\boldsymbol{s})} - 1$$

Reef locations



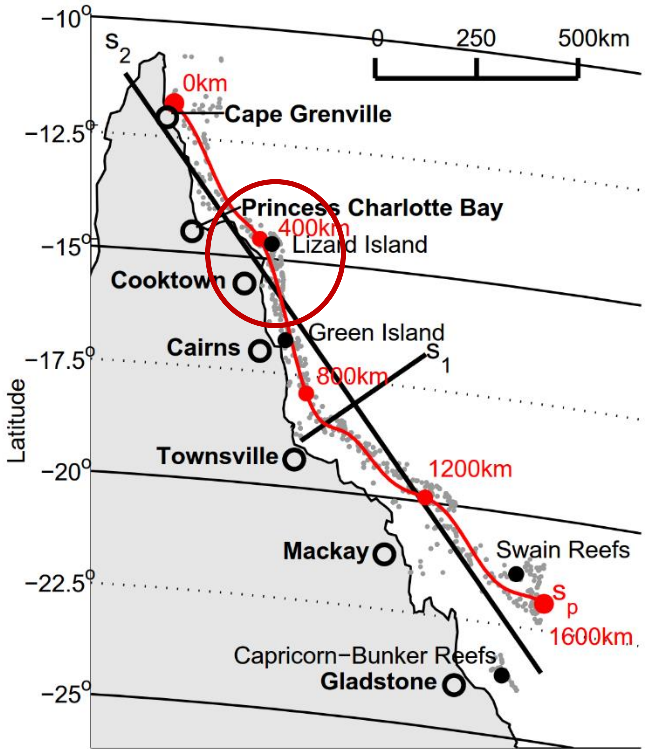
Spatial relative change



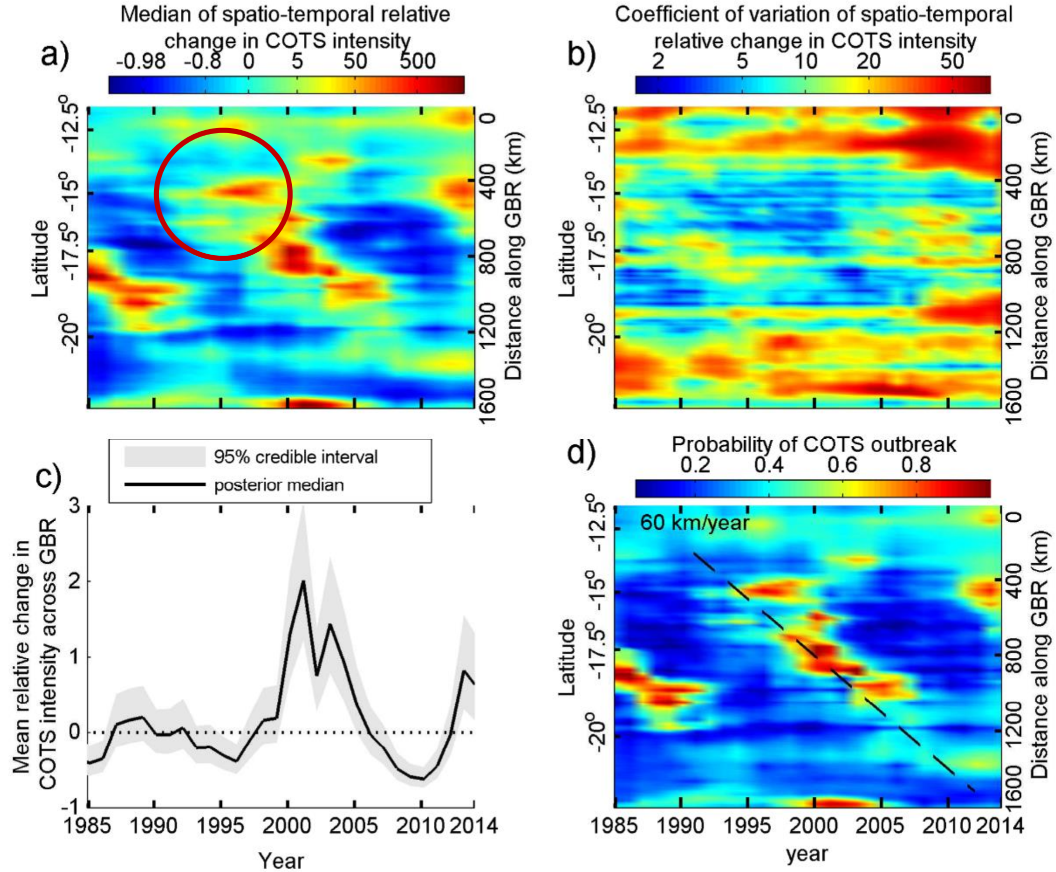
Spatio-temporal relative change in intensity:

$$e^{g(s,t)} - 1$$

Reef locations

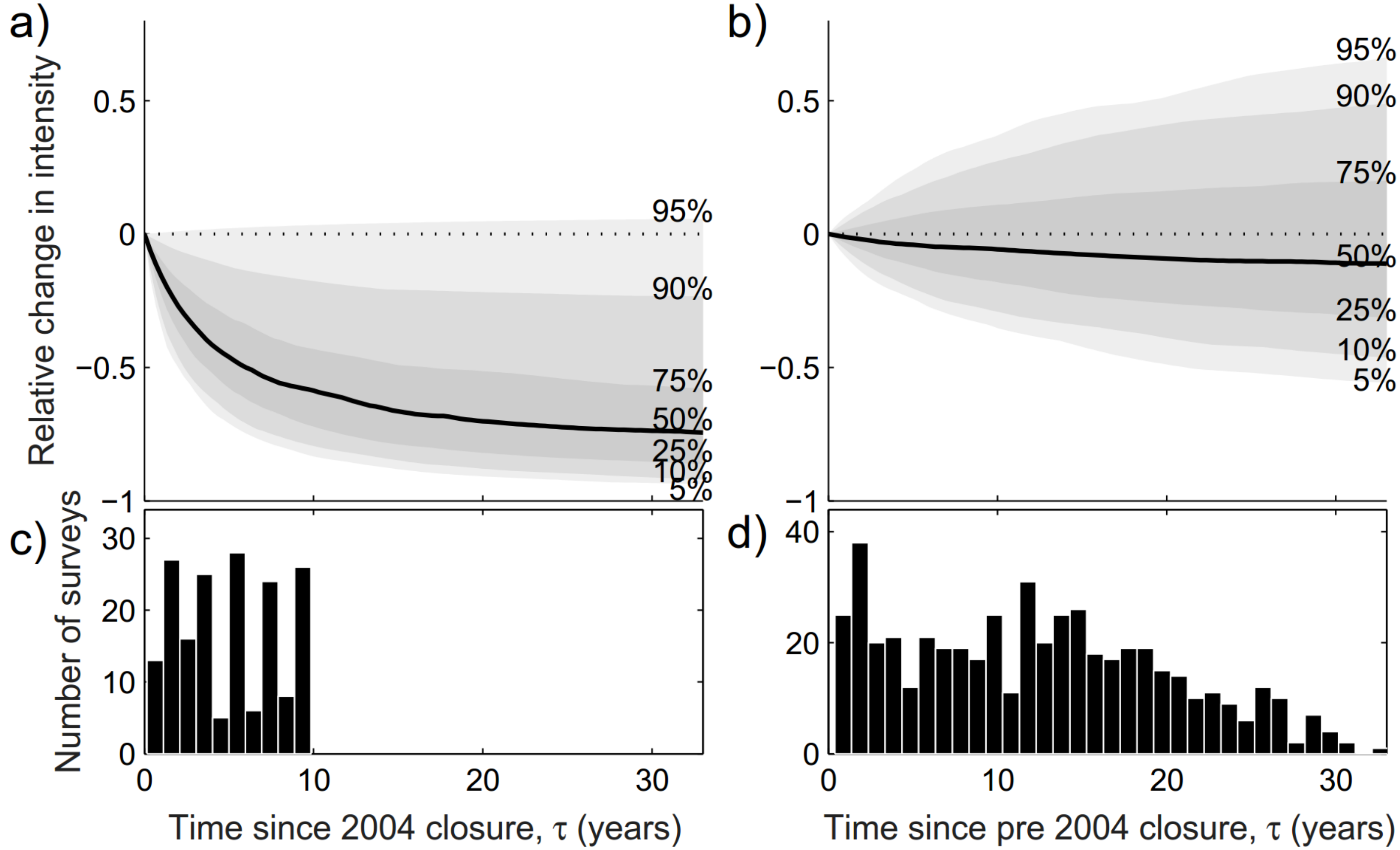


Spatio-temporal relative change



Effect of fishing closure:

$$e^{f_{\text{closure}}(\tau_{i,\text{pre04}},\tau_{i,04})} - 1$$



Discussion

- The model revealed previously unknown areas of constant high COTS intensity
- With the new definition of an outbreak we were able to support some of the hypotheses of progression of COTS outbreaks
- The results support also the hypothesis that fishing closures decrease the COTS abundance
- The results “visualize” patterns of COTS abundance that help management and further biological studies

Thank you!

- Jarno Vanhatalo, Geoffrey R. Hosack and Hugh Sweatman (in press). **Spatio-temporal modelling of crown-of-thorns starfish outbreaks on the Great Barrier Reef to inform control strategies**. *Journal of Applied Ecology*
- Jarno Vanhatalo, Jaakko Riihimäki, Jouni Hartikainen, Pasi Jylänki, Ville Tolvanen, Aki Vehtari (2013). **GPstuff: Bayesian Modeling with Gaussian Processes.** *Journal of Machine Learning Research*, 14:1175-1179.
- Jarno Vanhatalo, Lari Veneranta and Richard Hudd (2012). **Species Distribution Modelling with Gaussian Processes: a Case Study with the Youngest Stages of Sea Spawning Whitefish (Coregonus lavaretus L. s.l.) Larvae**. *Ecological Modelling*, 228:49-58.

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