Battling Bluetongue and Schmallenberg virus: Local scale behavior of transmitting vectors

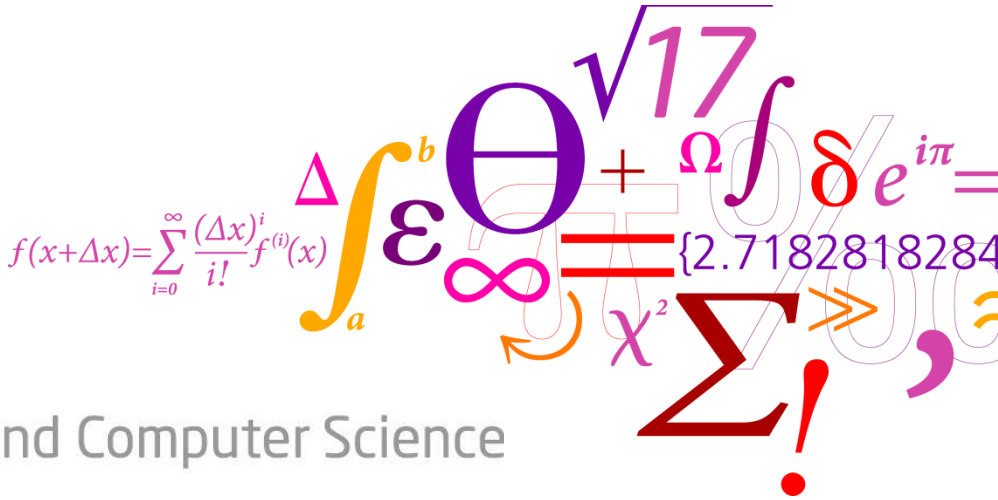
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Infectious Diseases, London

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Bluetongue and Schallenberg

- viral diseases that affects ruminants;
- mainly sheep, cattle and goats.

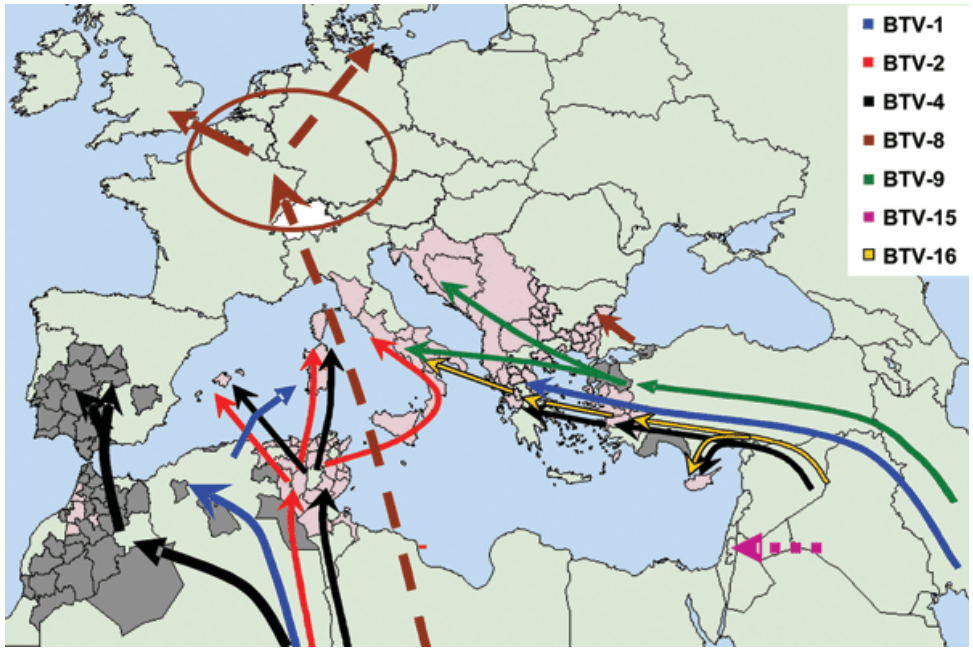






Epidemiology

- 2006: BTV-8 reaches Northern Europe.
- 2007: First case in Denmark.
- 2012: Schallenberg virus reaches Northern Europe (and Denmark).



Routes of introduction of different BTV serotypes and individual virus strains. From Wikipedia.

Epidemiology

- Vector borne: Transmitted by biting midges: *Culicoides*.

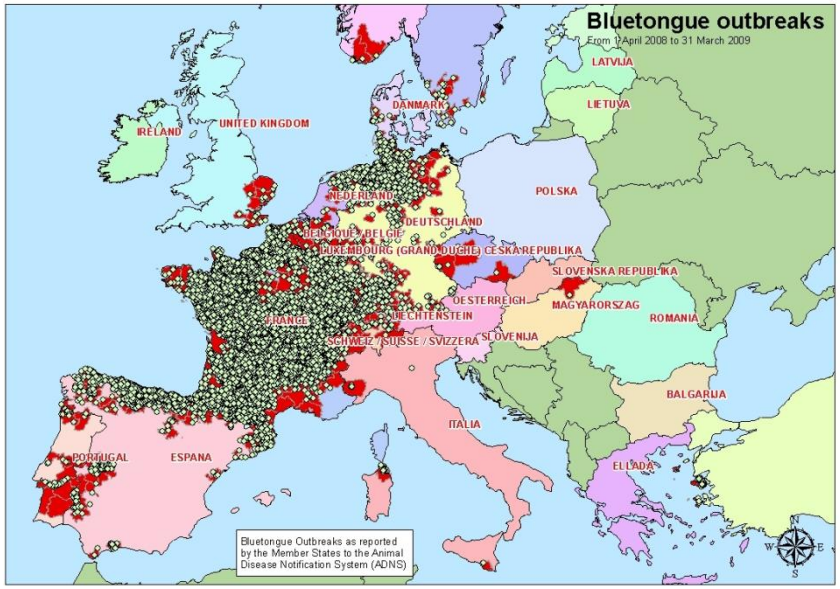


- *Vector species:*
  - *Culicoides imicola (Southern Europe);*
  - *Culicoides schultzei (Africa, Asia, Australia and Southern Europe).*

- *Progression northwards first ascribed to climate changes, but it has been realized that new* vectors, ***Culicoides pulicaris*** and ***Culicoides obsoletus***, can acquire and transmit the viruses.

Bluetongue and Schallenberg diseases – Impact

- Very costly for the industry and society: A Bluetongue outbreak such as the Belgium outbreak in 2006-7 has been estimated to cost **£485 million** and **10.000 jobs**, should a similar outbreak occur in the UK (Webb 2008).



Bluetongue outbreaks in the EU 2008-2009
(European Commission 2009)

Containing the diseases

- No efficient treatment.
- Containing the diseases:

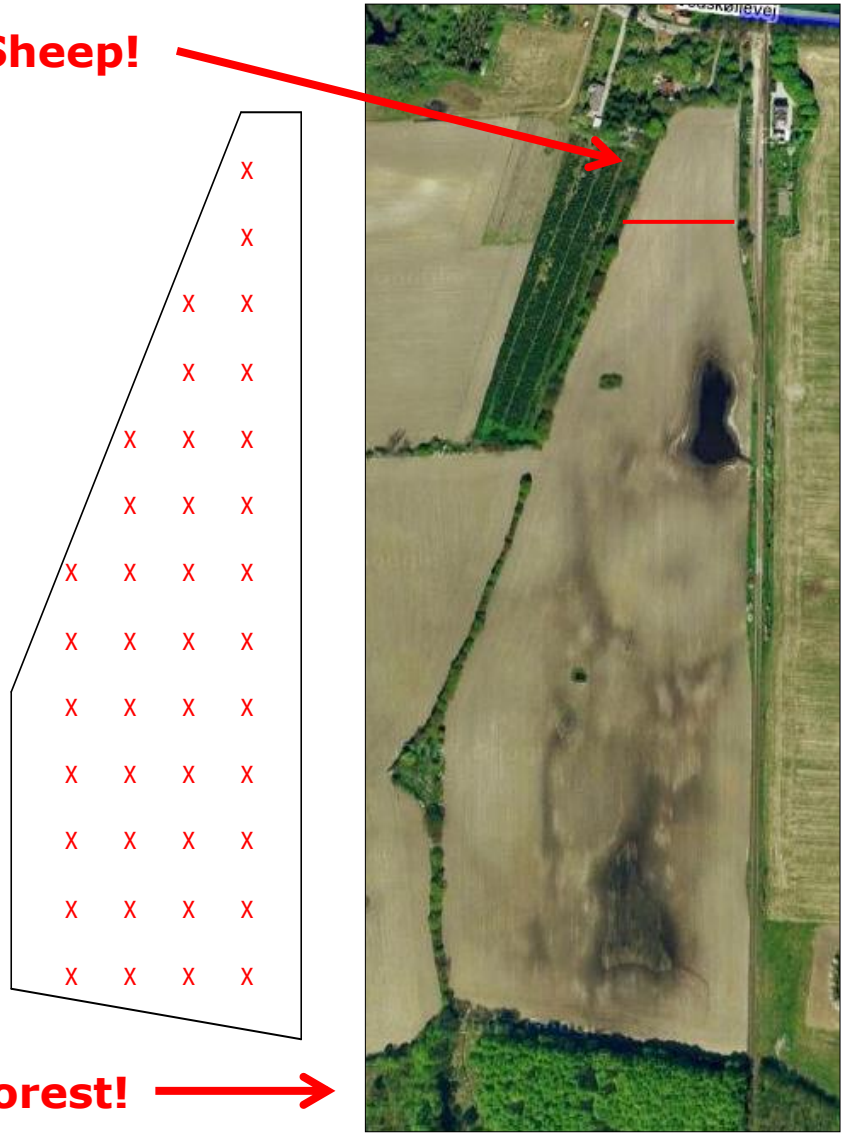
- Quarantine;
- Inoculation with live virus; BTV-8 vaccines are available now but the immunization period is not clear;
- Containing the vector.

Containing Bluetongue locally in the presence of host animals

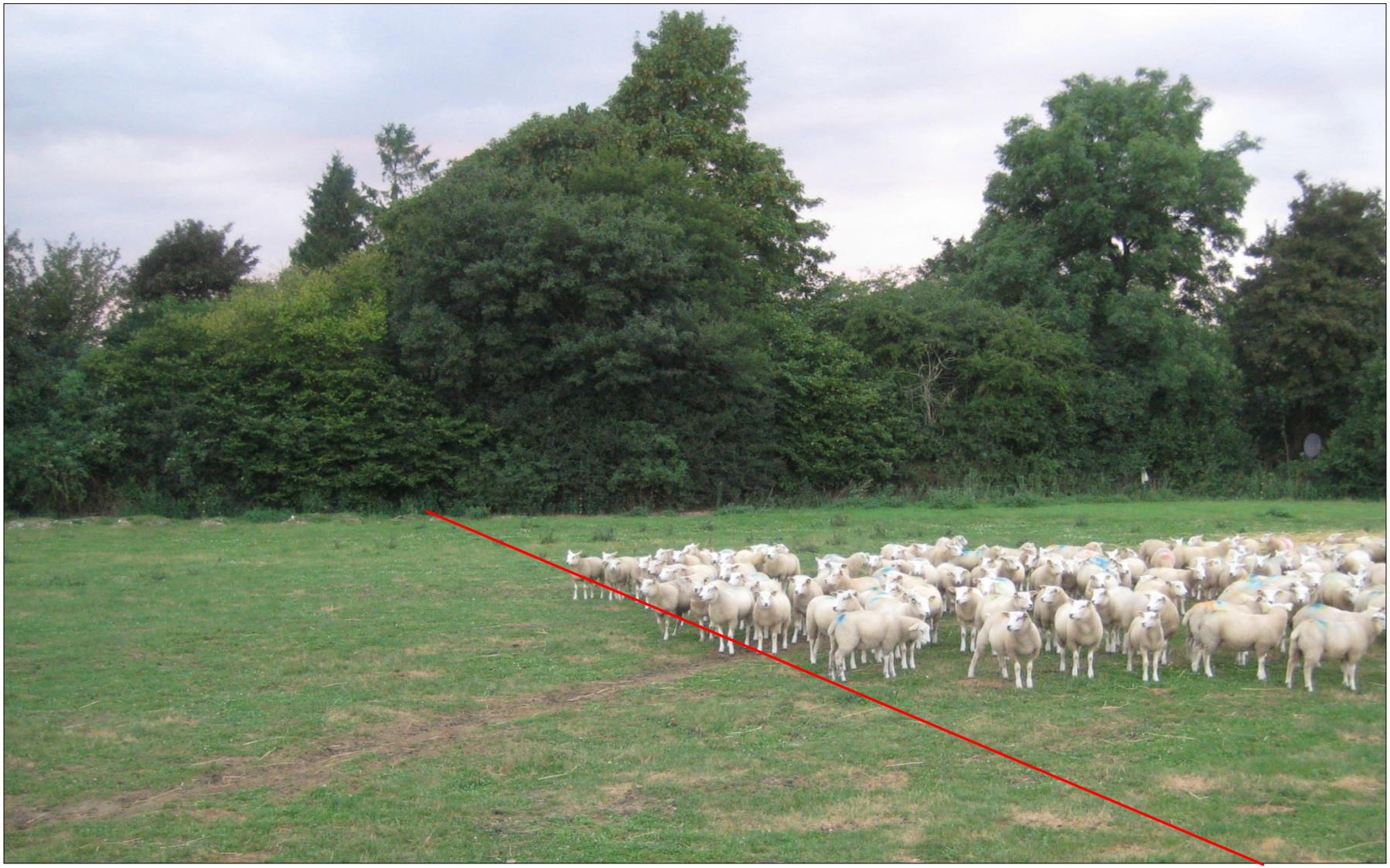
- Placement of 50 light traps;
- Running all light traps 4 nights pr. week;
- Emptying light traps and conserving *Culicoides* for later analysis;
- Placement of host animals during nights;



Battery operated CDC UV trap



Host animals in upper part of field



Data – covariates

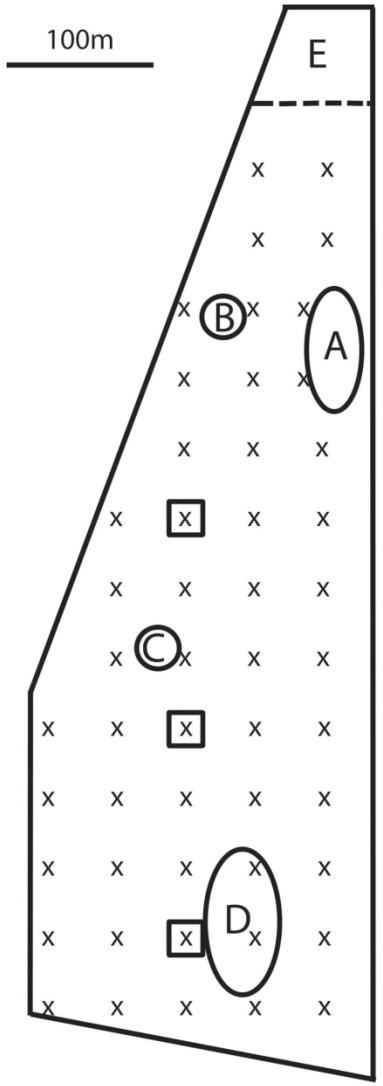
- Which variables means something for where the vector is?

- Breeding sites
- Distance to sheep
- Humidity
- Precipitation
- Sheep transect
- Temperature
- Wind speed

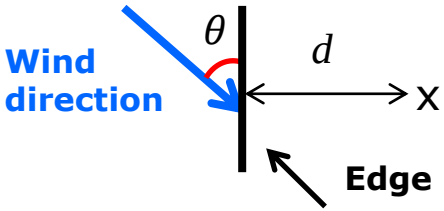
A-D: Breeding sites

E: 260 Sheeps kept here at night

[x] : Sheep transect with 1 sheep in a 3x3 m enclosure on 3 catch nights



- Wind breaks: $\text{wind speed} \times \sum_{i=1}^{4} |sin(\theta_i)| 1_{\{\theta \in (0;\pi)\}} / d_i$
- Sheep scent: $\text{wind speed} \times |sin(\theta)| 1_{\{\theta \in (0;\pi)\}} / d$



Edge i of field (Wind breaks)/

Area E separator (Sheep Scent)

Data

- Female *Culicoides obsoletus* and *Culicoides pulicaris* were counted in each light trap each day;

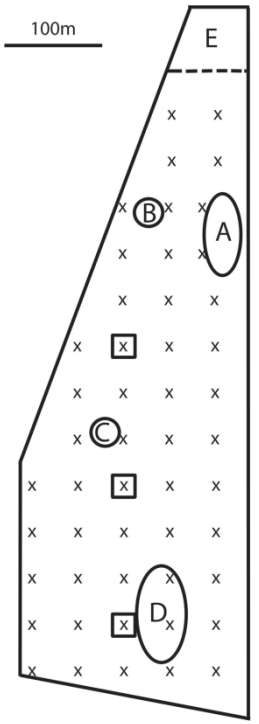
- Problem: For 8 catch nights, due to time constraints, only 50% of the trap catches were counted (checkerboard pattern).

- All:

16 catch nights,
530 trap catches,
15166 female *Culicoides pulicaris* caught;
4488 female *Culicoides obsoletus* caught.

Original analysis

- Analysed with a lattice model (conditional independence model), through successive conditioning. Solves problem with missing values.



Major problem

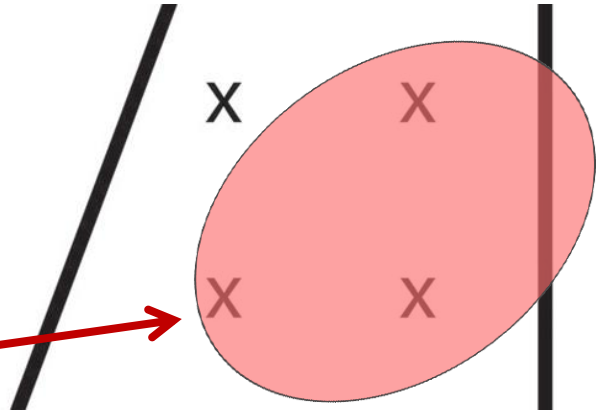
The many missing values makes it difficult to interpret dependencies, and hard to model dependencies across the spatio-temporal domain.

Details: Kirkeby et al. (2013).

Spatial and temporal correlation

- Standard regression methods do not apply, because the data points are **NOT stochastically independent**: They are **correlated**.

- **Spatially:** A high catch in one trap likely means many midges in the area, and thus an increased chance that neighboring traps will catch many midges as well. **The further away in distance, the lesser the effect**.

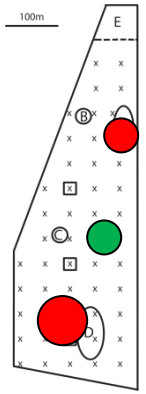


- **Temporal:** A high catch in one trap likely means many midges in the area. They may also be there tomorrow, and may have been there yesterday. **The further away in time, the lesser the effect.**

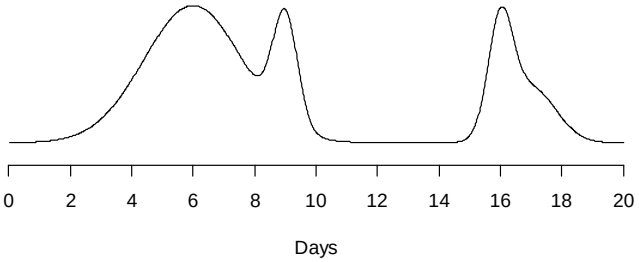
Standard regression methods of estimation can't handle varying correlation.

Re - analysis

- Specify the covariance structure directly:
- **Spatial dependence** that accounts for clustering in space;



- **Temporal dependence** that account for clustering in time;



- **Spatio-temporal dependence** that combines the two.

Re - analysis

- Specify reference points $\mathrm{x}_0 = (x_{01}, x_{02})$ and T_0 in space and time.

$\mathbb{X}_{i,j,k}$ is catch at **horisontal distance *i***,
vertical distance *j*,
temporal distance *k*
from the reference points.

$\mathbb{Y}_{i,j,k} = \log(\mathbb{X}_{i,j,k} + 1)$.

Then the correlation between any $\mathbb{Y}_{i,j,k}$ and $\mathbb{Y}_{r,s,t}$ is modeled as

$$cor(\mathbb{Y}_{i,j,k}, \mathbb{Y}_{r,s,t}) = \rho^{\left\| \binom{i}{j} - \binom{r}{s} \right\|} \times \eta^{|k-t|}$$

Re - analysis

Take $\Sigma(\rho, \eta)$ as the matrix

$$\Sigma(\rho, \eta)_{(i,j,k),(r,s,t)} = cor\left(\mathbb{Y}_{i,j,k}, \mathbb{Y}_{r,s,t}\right)$$

And model $\mathbb{Y} = \left(\mathbb{Y}_{i,j,k}\right)$ with a multivariate normal model,

$$Y \sim N\left(X\beta, \sigma^2 \Sigma(\rho, \eta)\right)$$

Where

- X is the design matrix constructed from covariates,
- β is the vector of effect parameters,
- σ^2 is the residual variance.

Re - analysis

Log-likelihood:

$$\ell(\beta, \sigma^2, \rho, \eta) = -\mathrm{n} * \log(\sigma^2) - \log\Big(det\big(\Sigma(\rho, \eta)\big)\Big) - \sigma^{-2}(\mathbb{Y} - X\beta)^T \Sigma(\rho, \eta)^{-1}(\mathbb{Y} - X\beta)$$

Maximized using **Template Model Builder** (Kristensen, to appear).

https://github.com/kaskr/adcomp

Results

Covariate	Estimate (SD), obsoletus	Significance obsoletus	Estimate (SD), pulicaris	Significance pulicaris
Intercept	-354.4(17.9)	-	-384.7(9.7)	-
Distance to sheep	-4.80e-3(5.05e-4)	***	-4.05e-3(4.25e-4)	***
Squared distance to sheep	6.59e-2(6.92e-3)	***	6.42e-2(5.93e-3)	***
Precipitation	-68.0(3.4)	***	-73.2(1.69)	***
Turbulence	-190.8(10.8)	***	-206.2(5.2)	***
Humidity	1.07(0.05)	***	1.19(0.03)	***
Temperature	40.6(2.1)	***	43.7(1.1)	***
Squared temperature	-1.3(0.07)	***	-1.39(0.03)	***
Wind speed	1.84(0.2)	***	2.24(0.12)	***
Squared wind speed	-0.18(0.03)	***	-0.23(0.02)	***
Sheep transect	-	NS	0.44(0.10)	*
Breeding sites	-	NS	-	NS
Windbreaks	-0.12(0.05)	*	-	NS
Sheep scent	-	NS	-	NS
Windbreaks:Sheep scent	-	NS	-	NS
Sheep Scent: Distance to sheep	-	NS	-	NS

(Catch night dummies left out)

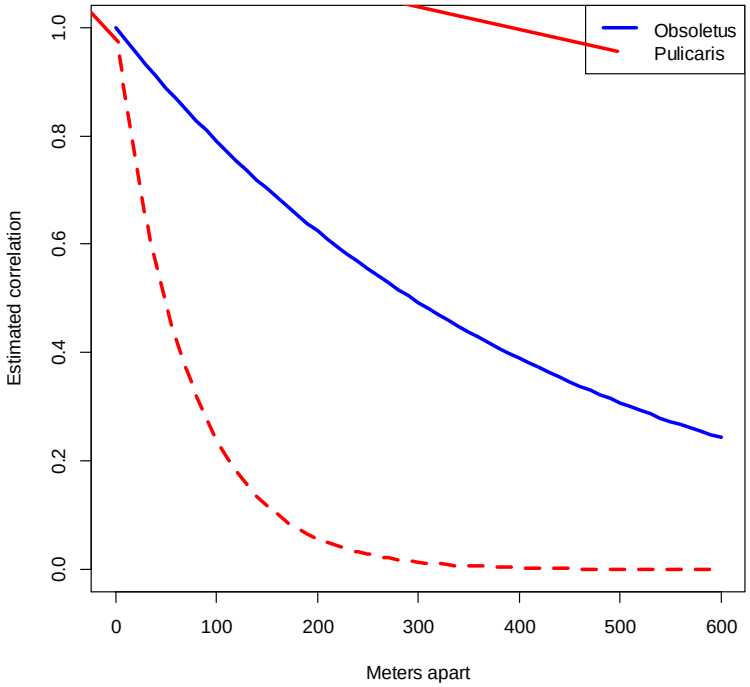
Results: Correlations and variances

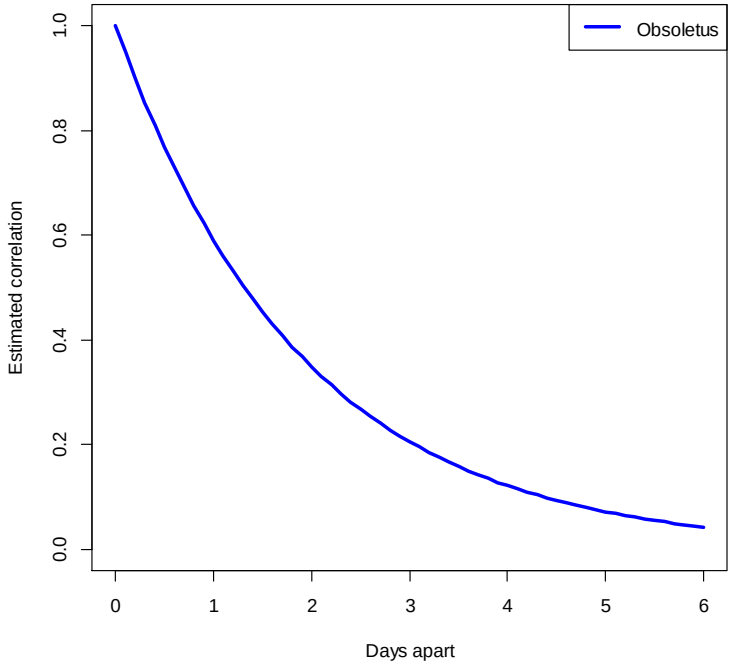
	Estimate obsoletus	Significance obsoletus	Estimate pulicaris	Significance pulicaris
Spatial correlation (100m's)	0.79	***	0.24	***
Temporal correlation (days)	0.59	**	-	NS
Residual variance	0.28	-	0.21	-

Original analysis

	Estimate obsoletus	Significance obsoletus	Estimate pulicaris	Significance pulicaris
Spatial correlation (100m's)	0.17	***	0.06	***
Temporal correlation (days)	-	NS	-	NS
Residual variance	0.69	-	0.65	-

Spatio and temporal correlations



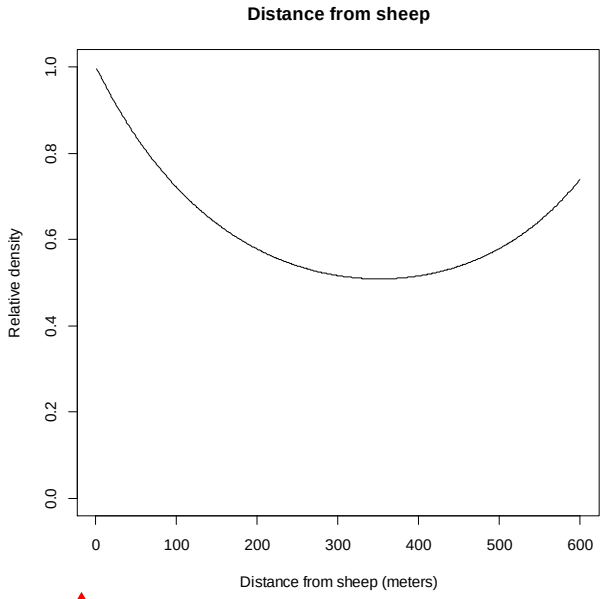


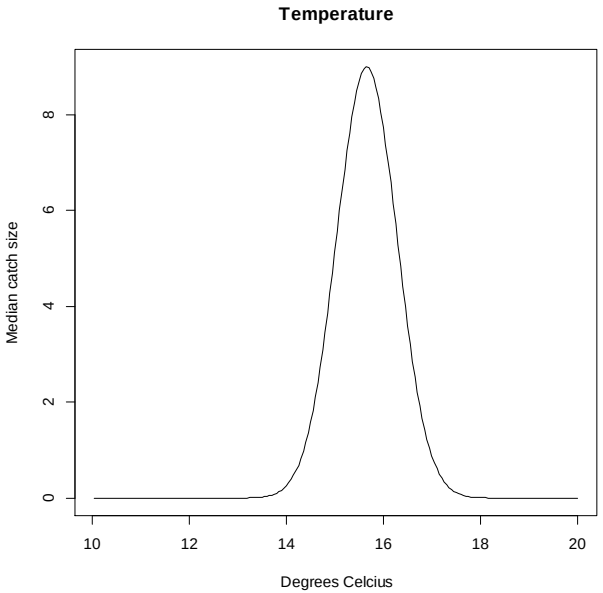
- The heavy *obsoletus* spatial correlation may suggest external sources of midges.
- The *pulicaris* spatial correlation may be ascribed to swarming.

Effects

- **No or limited effects:**
  - Breeding sites;
  - Windbreaks;
  - Sheep scent;
  - Sheep transect;
  - Specified interaction effects.

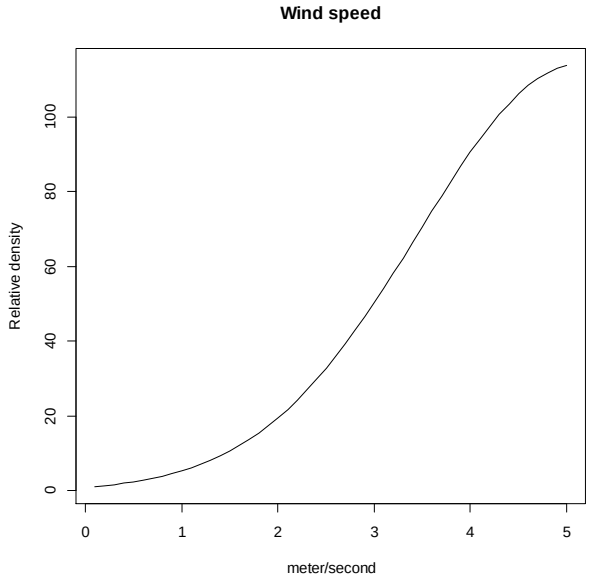
Nonlinear covariate effects





Sheep

Forest



Effects of distance to sheep, temperature and wind speed.

Conclusions

- **Critical conditions**: Humid, 14º-17º Celsius, and moderate wind.
- **Non-critical conditions**: Rainy, turbulent or no wind.
- Effects seems to be species independent.
- Special concern should be taken locally under critical conditions.
- The direct specification of correlations reveals much higher spatio-temporal correlations and reduces model error by a factor 2-3 on the log-scale.

Thank you for your attention







