UNIVERSITY OF EXETER

In association with the Met Office
and the Institute for Animal Health

The impacts of weather and climate change on the spread of bluetongue into the United Kingdom

Submitted by Laura Elizabeth Burgin to the University of Exeter
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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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Abstract

A large epizootic of the vector-borne disease bluetongue occurred in northern Europe from 2006-2009, costing the economies of the infected countries several hundreds of millions of euros. During this time, the United Kingdom (UK) was exposed to the risk of bluetongue by windborne incursions of infected *Culicoides* biting midges from the northern coast of mainland Europe. The first outbreaks which occurred in the UK in 2007 were attributed to this cause. Although bluetongue virus (BTV) no longer appears to be circulating in northern Europe, it is widely suggested that it and other midge-borne diseases may emerge again in the future, particularly under a changing climate.

Spread of BTV is strongly influenced by the weather and climate however limited use has been made of meteorologically based models to generate predictions of its spread to the UK. The extent to which windborne BTV spread can be modelled at timescales from days to decades ahead, to inform tactical and strategic decisions taken to limit its transmission, is therefore examined here.

An early warning system has been developed to predict possible incursion events on a daily timescale, based on an atmospheric dispersion model adapted to incorporate flight characteristics of the *Culicoides* vectors. The system's warning of the first UK outbreak in September 2007 was found to be greatly beneficial to the UK livestock industry. The dispersion model is also shown to be a useful post-outbreak epidemiological analysis tool.

A novel approach has been developed to predict BTV spread into the UK on climate-change timescales as dispersion modelling is not practical over extended periods of time. Using a combination of principal component and cluster analyses the synoptic scale atmospheric circulations which control when local weather conditions are suitable for midge incursions were determined. Changes in the frequency and timing of these large scale circulations over the period 2000 to 2050 were then examined using an ensemble of regional climate model simulations. The results suggest areas of UK under the influence of easterly winds may face a slight increase in risk and the length of the season where temperatures are suitable for BTV replication is likely to increase by around 20 days by 2050. However a high level of uncertainty is associated with these predictions so a flexible decision making approach should be adopted to accommodate better information as it becomes available in the future.

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Author's Declaration

The research contained in this thesis was partly carried out for a joint collaboration project between The Met Office and Institute for Animal Health funded by Defra (project SE4204 "The spread of bluetongue and related diseases by wind-borne vector *Culicoides*"). Chapter 3 presents the results for much of the Met Office contribution to this project.

The provision of data from field and laboratory experiments and expert advice regarding midge flight behaviour were provided by collaborators at the Institute for Animal Health, as detailed in separate sections in Chapter 3 entitled "midge data used in model development". Other work in this chapter regarding adaptation to the existing NAME model and its subsequent use was carried out solely by the author as detailed in the "model modifications" and results sections. This included writing new FORTRAN code, running the model, analysing the results and producing the images and data required for the early warning website.

All other research, presented in Chapters 4 and 5, was all carried out solely by the author.

Abbreviations

ADNS	Animal Disease Notification System
AHSV	African horse sickness virus
AWS	Automatic weather station
BL	Boundary layer
BTV	Bluetongue virus
CMIP	Coupled Model Intercomparison Project
Defra	Department for Environment, Food and Rural Affairs
ECMWF	European Centre for Medium-Range Weather Forecasts
EIP	Extrinsic incubation period
EHDV	Epizootic hemorrhagic disease virus
FBL	Flight boundary layer
GCM	General (or Global) Circulation Model
GHG	Greenhouse gas
IAH	Institute for Animal Health
IPCC	Intergovernmental Panel on Climate Change
IPCC AR4	The Fourth Assessment Report of the Intergovernmental Panel on Climate Change
IPCC FAR	The First Assessment Report of the Intergovernmental Panel on Climate Change
MME	Multi-model ensemble
MSLP	Mean sea level pressure
NAME	Numerical Atmospheric-dispersion Modelling Environment
NAO	North Atlantic Oscillation
NDVI	Normalized Difference Vegetation Index
NWP	Numerical weather prediction
OIE	World Organisation for Animal Health (formerly the Office International des Epizooties)
PCA	Principal component analysis
PCs	Principal components

PDF	Probability density function
PP	Pressure pattern
PPE	Perturbed physics ensemble
PRUDENCE	Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects
RCM	Regional climate model
RPC	Rotated principal component
SRC	Standardized regression coefficient
UKCP09	UK Climate Projections 2009
UM	Unified model
Z	Zulu Time or Universal Coordinated Time

Symbols

C	Concentration
$d\xi$	Increment of a random process
Δt	Timestep
K	Eddy diffusivity
κ	Molecular diffusivity
M_1	Temperature
M_2	Wind speed
M_3	Presence of rain
t	Time or Julian Day
τ_u	Lagrangian timestep in the horizontal
τ_w	Lagrangian timestep in the vertical
u	Instantaneous wind velocity
u'	Fluctuating component of the instantaneous wind velocity
$\bar{u}$	Mean wind
$u(x, y, \eta)$	Wind velocity vector
$u'(x, y, \eta)$	Turbulence velocity vector
$u_l^{'}(x, y, \eta)$	Low-frequency meander vector
x	Position in the x-direction
$x(x, y, \eta)$	Particle position vector
σ_u	Horizontal velocity variance
σ_w	Vertical velocity variance
σ_{eff}	Effective velocity variance
μ	Expected number of midges