Institution: University of Liverpool

Unit of Assessment: 17A Geography, Environmental Studies and Archaeology: Geography and Environmental Studies

Title of case study:

Modelling the impacts of climate on infectious disease – supporting better disease control

1. Summary of the impact

Earth Surface Processes and Environmental Change (ESPEC) Research Group researchers have developed the Liverpool Malaria Model (LMM). When integrated with various short range and long term climate models as part of wider research into a complex cross cutting 'grand challenge', the LMM helps decision makers understand when an area is likely to become at risk from malaria in short and over longer time frames by indicating which areas are likely to become centres for epidemics. The impact of the research has been to advance policy makers' awareness and understanding of this complex issue, enhancing their capacity to manage associated risks.

2. Underpinning research

It is estimated that malaria reduces GDP growth by at least 3% annually. Research by ESPEC (Morse, 2000-13; Jones, 2004-13 and Caminade, 2008-13) enabled robust climate-driven malaria prediction systems to be developed, allowing decision makers to get a better understanding of changing risks to economic growth arising from malaria epidemics driven by climate change. This matters given public concern about the reliability of science in predicting long term climate change, and the implications in predicting changes in disease vectors. .

By using seasonal weather forecasts in Africa, weather anomalies can be reliably predicted for four to six months ahead for several regions and for most years. As a result, the methodology enables prediction of disease vectors over longer timescales than had previously been the case. ESPEC researchers were part of a team developing seasonal weather forecasting models in order to predict changing disease trajectories, creating more robust seasonal malaria forecasts for west and southern Africa. This allows prediction of the likelihood of malaria moving into areas where it is not endemic, e.g. along the fringes of the Sahel and southern Africa (Thomson et al. 2006). The ESPEC team was responsible for developing and integrating their dynamic malaria model (Hoshen and Morse, 2004) into an ensembles prediction system (EPS) bringing together a wide range of data to provide assessments of the probable likelihood of there being a malaria outbreak, beyond the binary understandings of malaria being either endemic or absent. Early successes led to funding in FP5 DEMETER (Thomson et al 2006), and to further investment in FP6 in the ENSEMBLES and AMMA programmes and then in FP7 through QWeCI and impact in this REF period. This has led to malaria forecasting systems being developed locally for regional operational use since 2006, e.g. early work in Botswana is now contributing to a governmental strategic review of Botswana's malarial programme which commenced in 2008, supporting its objective of eliminating malaria by 2015. Most recently Jones and Morse (2012) have shown that even in areas with most unstable transmission, predictions can be made with several months lead time using the Liverpool Malaria Model (LMM) within a R&D EPS.

Research has focused on the climatic drivers of malaria in Africa, representing two integrated phases of development. Initially, the team developed a seasonal range (6 month lead times) state-of-the-art ensemble prediction system for Botswana, and verified the reliability of the system for predicting malarial vectors. Secondly, the team worked with climate model outputs projecting beyond one year towards the conditions projected in the latter half of this century (Ermert et al, 2012). The methodology was then adapted for use with other diseases in Europe. The ESPEC team further developed the system to make it more robust, through rigorous testing and development (ENSEMBLES project, Jones and Morse, 2010). This enabled the development of methodologies capable of understanding longer term changes in a range of disease vectors and associated pathogens with climate change in scientifically valid ways.

3. References to the research (indicative maximum of six references)

1. Hoshen, M.B. and **Morse, A.P.** (2004) A weather-driven model of malaria transmission, **Malaria Journal**, 3 (32) pp 14. doi:10.1186/1475-2875-3-32 cited 136 times Google Scholar 29 September 2013.
   Morse innovated model interfaces to allow the use of the model with climate data sets and helped test and run the model during its construction. Morse was line manager of Hoshen.
2. Thomson, M.C., Doblas-Reyes, F.J., Mason, S.J., Hagedorn, R, Connor, S.J., Phindela, T., **Morse, A.P.** and Palmer, T.N. (2006) Malaria early warnings based on seasonal climate forecasts from multi-model ensembles**. Nature**, 439, 576-579 doi:10.1038/nature04503 cited 246 times Google Scholar 29 September 2013. Morse developed novel processing algorithms and model output visualisations to use a malaria statistical model within the ensembles prediction system.
3. Jones A.E. and **Morse A.P.** (2010). Application and Validation of a Seasonal Ensemble Prediction System using a Dynamic Malaria Model, **Journal of Climate**, 23 (15), 4202–4215. doi:10.1175/2010JCLI3208.1 Morse acted as Jones' PhD supervisor, trained Jones to use the malaria model and discussed its structure and further developed the linkage to ensemble prediction systems.
4. Ermert V, Fink AH, **Morse AP**, Paeth H, (2012). The Impact of Regional Climate Change on Malaria Risk due to Greenhouse Forcing and Land-Use Changes in Tropical Africa. **Environmental Health Perspectives**, 120(1), 77-84: doi:10.1289/ehp.1103681 Morse further developed the malaria model with Ermert and transferred the use of ensemble systems to climate change time scales.
5. Jones, A.E. and **Morse, A.P.** (2012) Skill of ENSEMBLES seasonal re-forecasts for epidemic malaria prediction in West Africa, **Geophysical Research Letters**, 39, L23707, 5pp. doi:10.1029/2012GL054040 http://www.agu.org/journals/gl/gl1223/2012GL054040/2012GL054040.pdf Morse was Jones' line manager and had the initial idea which is the crux of the paper to look at forecasts skill on the endemic disease margins in areas with high interannual variability.
6. February 2010 to July 2013 EU FP7 project **QWeCI** – Quantifying Weather and Climate Impacts on Health in Developing Countries. 3,499,403 euros EC contribution to Liverpool £747,810 awarded to Andy Morse.

4. Details of the impact (indicative maximum 750 words)

ESPEC research has advanced policy makers' awareness and understanding of climate driven disease vectors, enhancing their capacity to manage risk. Preventing future harm that arises from malaria is evidenced through the examples below:

Seasonal Scales

The practical value of seasonal Ensemble Predictions Systems (EPS) has been recognised by the World Meteorological Organisation (WMO), and the wider seasonal forecasting community especially in Africa, for its ability to 'predict a probability distribution of climate scenarios and hence, peak times for malaria transmissions[(1)]. It has generated interest in the use of EPS at organisations such as ACMAD (*African Centre of Meteorological Applications for Development)*. Another impact of AMMA, and ongoing QWeCI and Healthy Futures EC Framework 6 and 7 projects is the development and consolidation of scientific capacity in the region. This led to better integration of regional decision makers and scientists in order to demonstrate the benefits, and ultimately the adoption of decision support tools such as LMM to 'lead to an outstanding impact to the policies' [(2)]. The usefulness of such systems enhanced interaction between climate scientists and humanitarian NGOs via the Humanitarian Futures Programme (HFP), including Christian Aid where Morse *"provided general guidance and advice to the NGOs …on issues related to climate change and livelihoods"* [(3)] in developing and using the products that are derived from the forecasting systems; this now forms UK government thinking for future development [(4).]

Multi-decadal Scales

LMM has been verified at seasonal scale prediction allowing use with Regional Climate Models (RCMs) for current climate and with RCM climate projections for Africa and Europe. It provides useful insight to risks in the current climate. Further diseases and vectors have been investigated with RCM runs for Europe most notably with interest from the NERC ENHanCE project for *Aedes albopictus* (Asian Tiger Mosquito) with the Health Protection Agency saying that the work *"is of critical importance to policy and planning for the potential incursion of this exotic mosquito into this country"* [5]. This work has been used to highlight dengue risk if the mosquito became endemic to parts of the UK as a result of climate change, "*the further importance of this work is that it helps identify those parts of the UK where we should focus our ongoing surveillance for this mosquito"* [5 and 7].

The Climate Services Agenda has come out of pioneering work as illustrated here and has shown societal value of integrated impacts modelling systems across multiple sectors. In a project led by the Tanzania Meteorological Agency, its DG, Agnes Kijazi, stated that weather forecasts can make a huge difference for the l0-12 million malaria patients. The main objective of the project was to further develop and apply DEMETER methodology of integrating seasonal forecasts and malaria statistics into an end-to-end early warning system for malaria outbreaks. A new database of clinical cases was collected and made available for the wider scientific community. The seasonal cycle of malaria outbreaks were determined and high risk areas identified [1]. This was highlighted in the WMO World Climate Research Programme's Open Science Meeting on Climate Research in Service to Society in Denver, October 2011, and the IGBP/DIVERSITAS/IHDP/WCRP and ESSP Planet Under Pressure 2012 meeting, the largest gathering of global change scientists leading up to Rio+20 with 3,018 delegates at the venue and over 3,500 attending via live webstreaming, providing scientific leadership to Rio 20+ in London, 2012, where Morse co-convened a session and co-authored a briefing paper [6].

Our malaria modelling work was cited in the WHO Roll Back Malaria Programme and its Progress and Impact Series report on Mathematical Modelling to Support Malaria Control and Elimination [8]. The usefulness of a diagram we developed, in the work above, illustrating our malaria model performance over a series of years of seasonal forecasts is noted in a report Foresight: Infectious Diseases for the Department of Business, Innovation and Skills, *'but if more long-term records of forecasts and outcomes such as this one were available, decision makers could learn and improve their decision over time. In future, scientists should routinely make available the track record of their predictions, and decision makers should insist on knowing the past reliability of the forecast before relying on it.'* [9]. We have also worked on various training workshops for decision makers, next generation scientists from Africa and with African village leaders and representatives "... *undertaken in Sénégal a workshop with regional decision makers and Ministry officials (the National Malaria Programme, National Veterinary Services). That meeting was instrumental to convince those that a decision support tool like LMM can be used operationally in public health"* [2]. In May 2013 the first operational EPS malaria modelling systems was developed using the LMM based operational seasonal forecasting 'System 4' at The European Centre for medium-Range Weather Forecasts [10].

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. Section 'Climate Models and Malaria' on the WMO website corroborates that technologies developed by Morse in earlier projects are now being used for forecasts.

2. Statement of support from the Director of the Physics Laboratory of the Atmosphere and the Ocean, Université Cheikh Anta Diop, UCAD, Senegal, corroborating the role of Morse in consolidating local scientists and their subsequent ability to convince regional decision makers of the operational advantages of LMM.

3. Statement of support from the Climate Advisor, Programme Performance (PP), Christian Aid, corroborating the impact of advice relating to climate change and livelihoods on Christian Aid programmes.

4. Future Climate For Africa proposed a major funding venture on climate resilient development for sub-Saharan Africa (DFiD, NERC) and corroborates the use of climate projection data to climate proof development projects which was not formerly the case. The work Morse undertook with NGOs helped to move this agenda see (3).

5. Statement of support from the Scientific Programme Head, Microbial Risk Assessment and Behavioural Science, Emergency Response Department, Health Protection Agency, Public Health. This corroborates the use of Morse's work in policy and planning for potential future scenarios of mosquito incursion to the UK, including development of current guidance for on-going surveillance.

6. At the Planet Under Pressure conference (a large international meeting of over 3000 delegates), where 9 Policy Briefs were produced, the brief on global health (Morse was co-author) went to the Rio +20 United Nations Conference on Sustainable Development, June 2012. This policy brief highlighted the need for global action on emerging diseases impacted by global environmental change, thus making a case at a high-level geopolitical forum.

7. Section 8.3.8 Climate suitability for the Aedes albopictus in Europe: recent trends and future scenarios' (page 175) of the report "Health Effects of Climate change in the UK 2012", published by The Health Protection Agency ',corroborates the inputs of Morse on modelling climate impacts on Aedes albopictus distributions (Asian Tiger mosquito).

8. Page 37 of the WHO report 'Mathematical modelling to support Malaria control and elimination', references 'Hoshen and Morse linked a model of climate to a model of malaria transmission', stating that using mathematical models of malaria is important for impact and that seasonality is important in malaria models. This corroborates that Morse was driving malaria models from climate models.

9. Figure 5.4 and quote from section 5, page 99 of the BIS report demonstrates the importance of the work on communication of seasonal malaria forecasts outcomes by Morse.

10. Evidence to demonstrate the transition to an operational seasonal forecasting system at the European Centre for Medium-Range Weather Forecasts using the Liverpool Malaria Model. Morse has shown the ability to go from an R&D impact to a fully operational environment.