SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Use and value of ECMWF short-range and seasonal forecast products for developing countries in terms of end-user impact variables
Computer Project Account:	spitP4DC
Start Year - End Year :	2016 - 2018
Principal Investigator(s)	Adrian Mark Tompkins
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Summary of project objectives

(10 lines max)

The project extension focussed on the implementation of a pilot malaria forecasting system for Africa based on the use of the extended EPS and the Seasonal Forecasting system 4 to drive the ICTP's dynamical malaria modelling system VECTRI and to evaluate this for specific countries in Africa where data was available. The main countries in which the system was to be evaluated were Malawi, Rwanda and in particular Uganda, where high quality sentinel site data was also available.

Summary of problems encountered

No problems encountered in terms of the facilities at ECMWF. Due to a lack of staff available at ICTP as EU funding came to an end, not all project objectives were achieved within the timeframe proposed during the extension request.

Experience with the Special Project framework

As stated in earlier reports, the facilities at ECMWF are second to none, and issues with setting up scripts and code on the ECMWF system were always resolved swiftly with the aid of the staff at ECMWF who are extremely able and responsive.

Summary of results

The malaria modelling system was upgraded to use ECMWF system 4 seasonal forecasts (SYS4) and the malaria model was also upgraded at the project outset to take advantage of improvements to the numerical solution of the equations. In this phase of the project, the model was then rerun with the ESP and SYS4 hindcast suite and evaluated in Uganda. The key publications produced within this project phase are summarized in turn:

a) Idealized testing of an earlier prototype

Tompkins, Adrian M., and Francesca Di Giuseppe. "Potential predictability of malaria in Africa using ECMWF monthly and seasonal climate forecasts." *Journal of applied meteorology and climatology* 54.3 (2015): 521-540.

This work took an earlier version of the ECMWF-based malaria forecasting system and examined the potential predictability of the malaria forecasts over Africa. The work took place in the previous round of the project and was reported on that project's final report. The work found that the skill of the ECMWF systems over Africa was greater in temperature than rainfall, and this was reflected in a malaria early warning skill of predicting upper or lower tercile events out to 3 or 4 months in advance.

b) Considerations necessary for implementing the in a health service operational context

A. M. Tompkins, Rachel Lowe, Hannah Nissan, Nadége Martiny, Pascal Roucou, Madeleine C. Thomson, and Tetsuo Nakazawa, 2018. Predicting climate impacts on health at sub-seasonal to seasonal timescales. In A. W. Robertson and F. Vitart, editors, *The gap between weather and climate forecasting: sub-seasonal to seasonal prediction*, page in press. Elsevier.

This book chapter considered the issues that need to be tackled when using a system such as the one developed within SPITP4DC is to be integrated into health planning policy. The chapter reports the work carried out within the project and discusses some of the bottlenecks that need to be resolved in order to operationalize such systems.

c) Development of a new ensembles-based genetic algorithm for calibration and parameter setting

A. M. Tompkins and M. C. Thomson, 2018. Uncertainty in malaria simulations due to initial condition, climate and malaria model parameter settings investigated using a constrained genetic algorithm. *Plos One*, in press

This work developed a new calibration technique, initially for the ECMWF EPS, but was implemented in the SPITP4DC system. This was based on an extension of the Monte Carlo genetic algorithm approach with a constraint applied to prevent calibrated parameters taken on values outside a prior assessed certainty (Fig 1). A novel approach was to extend the calibration to the driving climate parameters, thus allow the calibrating to act as a form of bias

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correction technique on the analysis or seasonal forecasts, in that the seasonal forecast fields can be adapted within their known error range, and also the spatial representativeness errors (see article for details), in order to maximize malaria prediction skill. In this method, each member of the model ensemble (VECTRI malaria model or alternatively the IFS, see new special project application), is run with a slightly different set of parameter settings. The fitness of the each model integration is assessed using a balanced weighting between the skill of the output, and a departure penalty function according to how far parameters are perturbed from their default settings (analogous to the first guess departure cost function in variational analysis systems). The next set of forecast ensemble members then choose their parameters from "parent" models where probabilities of parameter adoption are based on this fitness function. Mutation and cross-over allow effective search of the parameter space within the N-sphere of uncertainty around the default parameter vector.

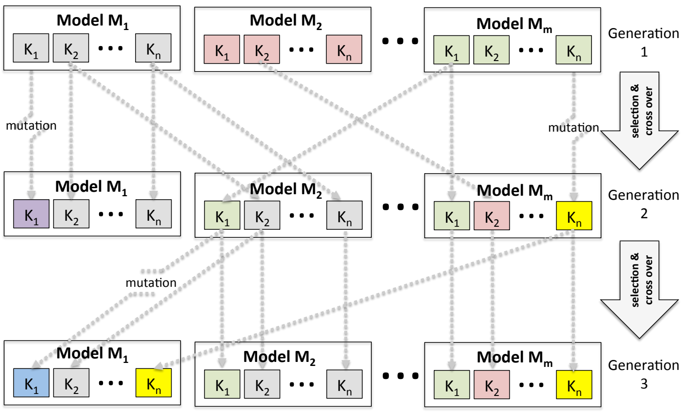

Figure 1: Schematic of the calibration approach developed for implementation in the SPITP4DC forecast system (from Tompkins and Thomson 2018, PLOS One).

The system permitted the model to reproduce the malaria variations in the East African highlands well in a location where the default model setup completely failed to sustain malaria transmission (Fig 2). A number of outbreaks in the early 90s and the 1998/99 events were well captured, although the model performs poorly in the early 80s. Separate analysis of the underlying climate from a nearby station demonstrated that during this period shows that climate could not drive the enhanced cases during 1979 and 1980.

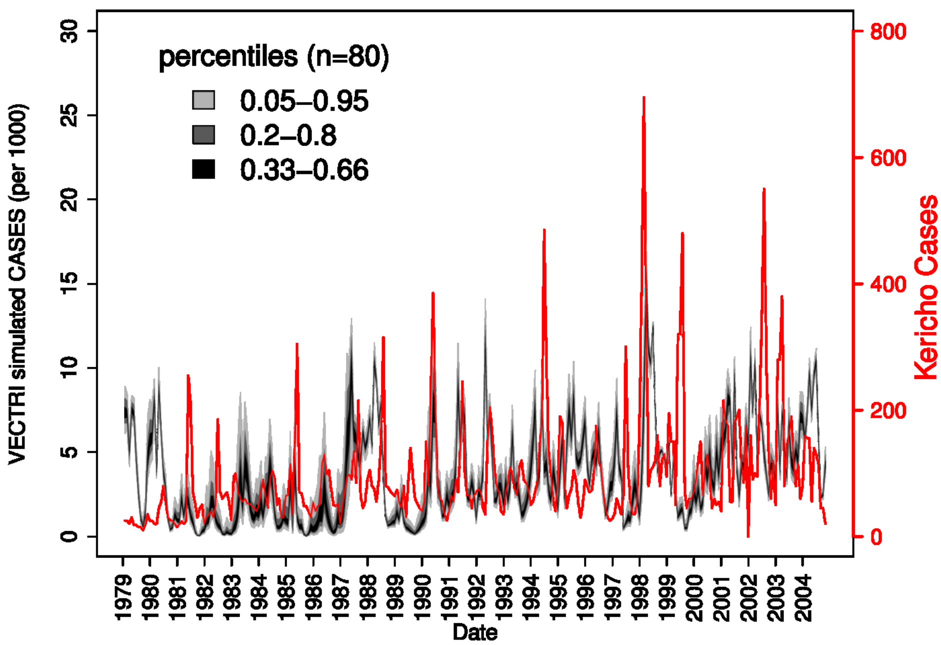

Figure 2: final calibration model ensemble compared to observed cases for Kericho in teh Kenyan highlands (from Tompkins and Thomson, 2018 PlosOne)

d) Evaluation of latest ECMWF-based system in Uganda:

A. M. Tompkins, F. J. Colón-González, F. Di Giuseppe, and D. B. Namanya, 2018. Dynamical malaria forecasts are skillful at regional and local scales in uganda up to four months ahead. *GeoHealth*, in review.

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The final version of the pilot system developed in this phase of the project was then rerun using ECMWF EPS and SYS4 forecasts with downscaling applied to produce a high resolution grid covering Uganda, where access to both district and high quality sentinel data had been achieved. This work, currently under review in the journal GeoHealth, showed that the ECMWF-driven model was able to capture the seasonal and interannual variations in both relative low lying (~800m altitude) and high altitude (>1300m) sentinel site locations within Uganda. The forecast skill assessed using district data was less conclusive, with approximately half of the districts showing significant skill at either 1 or 4 month lead times. Part of this is likely due to the poor quality of the health data compiled at district scales, where health facilities log suspected cases (fevers) and rarely perform examination of blood samples using either slide film or rapid diagnostic test kit methods. Moreover, it is also possible that differences in intervention actions and other socio-economic factors can dominate the impact of climate anomalies on transmission. This was also indicated by the fact that it was possible to identify neighbouring regions that share anomalies in both precipitation and temperature, the two key climate factors that impact malaria transmission, but whose malaria case history was completely contrasting. Often in these cases the model was able to reproduce the transmission anomalies in one district, but not the neighboring one, indicating the strong role of confounding factors.

The work extended the analysis of the forecast skill using a simple cost-loss, economic framework (Fig 3). These identified the range of cost-loss ratios and event rarity for which the system has positive economic value. It was argued that that step was necessary to allow such a system to be integrated into planning decisions, as in some cases, even if the anomaly correlation indicates the system is skillful, this does not always translate into a useful forecast. If cost of interventions is high relative to the economic impact of an outbreak, high forecast skill is required for the system use to be beneficial. Likewise, a low cost intervention would be routinely applied, as the cost of a miss, even if rare, would outweigh the savings made from non-intervention. The thresholds for these decisions depend on the frequency of the event considered (Fig. 3).

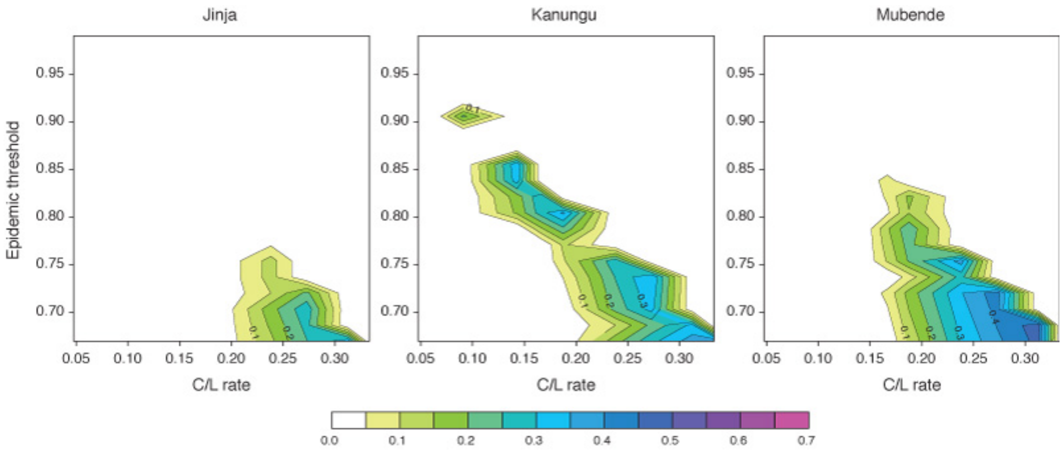

Figure 3: cost-loss economic analysis for malaria forecasts driven by ECMWF EPS and SYS4 for three locations in Uganda. Data is high quality confirmed sentinel sites. From Tompkins et al. 2018 GeoHealth, in review, see publication for further details.

In summary, the main components of a ECMWF forecast driven malaria early warning system were coupled in an SMS suite and evaluated for a recent period for which high quality health data was available in Uganda. It is important to emphasize that this represents the first sub-national scale malaria forecast using a fully dynamical modeling system, and the system was proven to be skillful out to a lead time of between 3 to 4 months. In order to move to an implementation stage several publications considered some of the bottlenecks that need to be tackled in order to move towards operationalization of the system. In addition, the suite as presently implemented at ECMWF is somewhat out of date, using an earlier version of the malaria model, the SMS operational suite, and the SYS4 hindcast database. Further work is now required to update the system to the new software suite and implement some of the post-processing tools (e.g. the cost-loss analysis) into the suite. These final steps will be tackled in the final extension phase of this project outlined below.

Other sundry developments within the project phase with some connection to the SPITP4DC model suite:

a) Extension of package to use climate output in multimodel runs

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Paper used the model run framework, but substituted the SYS4 forecasts with bias corrected climate model runs for large-ensemble study of climate change impacts on malaria in Africa:

Leedale, J., **Tompkins, A. M**., Caminade, C., Jones, A. E., Nikulin, G., & Morse, A. P. (2016). Projecting malaria hazard from climate change in eastern Africa using large ensembles to estimate uncertainty. *Geospatial health*, *11*, 102-114

b) Extension to the model code for hydrology:

Not directly related to the project, but further extensions to the hydrology treatment, which were then merged into the SPITP4DC code.

Asare, Ernest O., et al. "A breeding site model for regional, dynamical malaria simulations evaluated using in situ temporary ponds observations." *Geospatial health* 11.1s (2016).
Asare, Ernest Ohene, Adrian Mark Tompkins, and Arne Bomblies. "A regional model for malaria vector developmental habitats evaluated using explicit, pond-resolving surface hydrology simulations." *PloS one* 11.3 (2016): e0150626

Publications resulting from or linked to the project:

Directly linked:

A. M. Tompkins, Rachel Lowe, Hannah Nissan, Nadége Martiny, Pascal Roucou, Madeleine C. Thomson, and Tetsuo Nakazawa, 2018. Predicting climate impacts on health at sub-seasonal to seasonal timescales. In A. W. Robertson and F. Vitart, editors, *The gap between weather and climate forecasting: sub-seasonal to seasonal prediction*, page in press. Elsevier.
A. M. Tompkins and M. C. Thomson, 2018. Uncertainty in malaria simulations due to initial condition, climate and malaria model parameter settings investigated using a constrained genetic algorithm. *Plos One*, in press.
A. M. Tompkins, F. J. Colón-González, F. Di Giuseppe, and D. B. Namanya, 2018. Dynamical malaria forecasts are skillful at regional and local scales in uganda up to four months ahead. *GeoHealth*, under revision.
A. M. Tompkins, F. Di Giuseppe, F. J. Coloń-González, and D. B. Namanya, 2016. A planned operational malaria early warning system for Uganda provides useful district-scale predictions up to 4 months ahead. In J.Shumake-Guillemot and L.Fernandez-Montoya, editors, *Climate services for health: Case studies of enhancing decision support for climate risk management and adaptation*, pages 130--131. WHO/WMO Geneva.
A. M. Tompkins and F. Di Giuseppe, 2015. Potential predictability of malaria using ECMWF monthly and seasonal climate forecasts in Africa. *J. Appl. Meteor. Clim*, **54**:521--540.

Related:

F. J. Colón-González, **A. M. Tompkins**, R. Biondi, J. P. Bizimana, and D. B. Namanya, 2016. Assessing the effects of air temperature and rainfall on malaria incidence: an epidemiological study across Rwanda and Uganda. *Geospat. Health*, **1**:DOI: 10.4081/gh.2016.379.
Ernest O. Asare, **A. M. Tompkins**, Leonard K. Amekudzi, and Volker. Ermert, 2016. A breeding site model for regional, dynamical malaria simulations evaluated using in situ temporary ponds observations. *Geospat. Health*, **11**:DOI: 10.4081/gh.2016.390.
Ernest O. Asare, **A. M. Tompkins**, Leonard K Amekudzi, Volker. Ermert, and Schuster R., 2016. Mosquito breeding site water temperature observations and simulations towards improved vector-borne disease models for Africa. *Geospat. Health*, **11**:DOI: 10.4081/gh.2016.391.
E. Asare, **A. M. Tompkins**, and A. Bomblies, 2016. Evaluation of a simple puddle breeding site model for malaria vectors using high resolution explicit surface hydrology simulations. *Plos One*, **11**:http://dx.doi.org/10.1371/journal.pone.0150626

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

A project extension has been requested. This mainly concerns technical developments of the suite to bring it up to date at ECMWF for a pilot test phase in Uganda. Thus in the extension, no supercomputing units are required, only system access to address the following objectives:

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- Replace the existing VECTRI suite with the updated model version that includes new parameterizations for immunity, local permanent hydrological features and migrations, and permits a calibration process for the model and driving temperature/precipitation fields.
- Replace the preprocessing/driving scripts with a new simplified interface, also migrating the scripts from Bash to python in the process.
- Migrate the suite from SMS to ECFLOW.
- Extend the driving model systems from ECMWF to also use UK Met Office and MeteoFrance seasonal forecasting systems available within Copernicus.
- Implement a dual access system to the forecasts, with the option of using the python api to access S2S and Eurosip (via Copernicus) to allow the suite to be easily exported to other institutes in Africa (using Seasonal systems only in this case).
- Develop a set of more refined output metrics, including also an economic analysis based on the cost-loss framework.

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