A climate and health partnership to inform the prevention and control of meningoccocal meningitis in sub-Saharan Africa: The MERIT Initiative

Abstract

Many human diseases are climate-sensitive: climate acting as an important driver of spatial and seasonal patterns, year-to-year variations (including epidemics), and longer-term trends. Although climate is only one of the many drivers of both infectious and non-infectious disease, public health policy makers and practitioners are increasingly concerned about the potential impact of climate change on the health of populations.

The MERIT Initiative was launched in 2007 as a multi-sectoral partnership to provide a platform for enabling health specialists (public health specialists, epidemiologists, immunologists, microbiologists, demographers, etc.) and climate and environment specialists to work together to help solve a pressing health problem. The main objective of the initiative was to address meningococcal meningitis epidemics in Africa in the context of perceived environmental, biological, economic and demographic influences. The effort is designed to create new knowledge that can be used to improve the current (reactive) and future (preventive) vaccination strategies.

Preliminary results of this research to policy and practice consortium have advanced the understanding of how climate-related information can be tailored to inform and where possible strengthen public health decisions. Specifically, the MERIT experience to date indicates new evidence on the contribution that climate and environment make to the spatio-temporal distribution of meningococcal meningitis and demonstrates a multi-sectoral strategic approach to the creation of evidence, together with the development of a cumulative knowledge base. The MERIT Initiative is establishing an effective means for the dissemination of new knowledge and provides a platform to facilitate access to this knowledge by public health practitioners. These developments, along with an increase in the uptake of evidence in both policy and practice have the potential to impact health outcomes in vulnerable at-risk populations in Africa's Meningitis Belt.

The collaborative partnership model of MERIT provides an innovative framework to support public health preparedness and control strategies for climate sensitive diseases. Public health decision-makers have been willing to explore unfamiliar territory and opportunities for improving well-established control strategies by leveraging new knowledge and expertise from other disciplinary communities including climate and environmental researchers. Equally important have been the investments made by a multi-disciplinary research and practice community to adapt research projects in line with the evolving public health strategy across the Meningitis Belt. The lessons learned from the MERIT project offer valuable input and new ideas for improving global public health strategies for other climate and environmentally sensitive epidemic prone diseases.

A climate and health partnership to inform the prevention and control of meningoccocal meningitis in sub-Saharan Africa.: The MERIT Initiative

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Introduction

With increasing recognition of the importance of climate as a driver of many infectious disease occurrences and the potential for climate change to exacerbate global health concerns (61st World Health Assembly, Agenda Item 11.11, Climate Change and Health WHA61.19, May 19-24, 2008) there is growing interest from the climate and environmental communities to contribute knowledge and resources towards improving climate sensitive health outcomes. The scientific literature on the impact of climate on infectious diseases transmission dynamics (including parasitic, viral and bacterial pathogens such as malaria, leishmaniasis, schistosomiasis, leptospirosis, dengue rotavirus, meningococcal meningitis, etc) indicates significant research interest in this area (Kelly-Hope; Thomson 2008). However the public health community lags behind others in the use of climate and environmental information for climate-sensitive decision-making. Recent developments in climate science and, more recently, climate services, along with new technologies for data management, analysis and sharing provide unprecedented opportunities for rapidly advancing this area. However, new developments must be responsive to the real needs of the global health decision-making community and empower their associated research and practitioner communities if this potential is to be fully realized.

Problem Identification – Epidemic meningitis in sub-Saharan Africa

Epidemic bacterial meningitis (causal agent *Neisseria meningitidis, Nm*) devastates the lives of individuals and communities across the 'Meningitis Belt' of Africa, a sub-Saharan zone extending from Senegal to Ethiopia and first described by Lapeyssonnie in 1963 (Lapeyssonnie 1963). This bacteria is transmitted through respiratory droplets throughout the year but invasive disease and associated epidemics are largely restricted to the dry season (Greenwood et al. 1985). The mechanism by which environmental and climatic factors may influence meningitis epidemic occurrence remains unclear; the most common hypothesis for this role is that physical damage to the epithelial cells lining the nose and throat in hot, dry and dusty conditions permits the easy passage of the bacteria (found here frequently in asymptomatic form) into the blood stream causing invasive disease (Greenwood 1999). It has also been hypothesized that meningitis epidemics may be preceded by viral infections (also associated with specific climatic conditions) which may facilitate the transition from carrier to case (Mueller et al. 2008). *Neisseria* bacteria need iron to grow and become virulent (Noinaj et al. 2012) and it has been postulated that the mineralogical properties of dust aerosol (especially the iron content) may also facilitate transition (Thomson et al. 2009). Many non-climatic factors have also been associated with epidemics and include new bacterial strains, overcrowding, population movement etc.

The disease has severe social and economic consequences at the individual, household and community level and is widely feared because of its rapid onset, high mortality rate and frequent long term sequelae (Colombini 2009). The need for rapid vaccination in response to epidemics means that health staff are diverted from other important service activities creating an additional burden to the health sector (Colombini 2011).

Current and emerging control strategies

Historically, meningitis control activities in Africa have largely relied on the early identification of epidemics followed by a rapid deployment of polysaccharide vaccines (Anon 2000). This 'reactive' strategy has meant that people at risk of being infected have only been immunized in an emergency situation once a meningitis outbreak has started. The effectiveness of the reactive strategy can determine whether an outbreak is controlled or risks spreading to neighbouring districts and or countries.

Thresholds have been developed to inform the decision process as part of the reactive vaccination strategy. The epidemic threshold distinguishes a situation that is likely due to seasonal fluctuation from a situation that will develop into an epidemic. Implementing mass immunization campaign in any situation that is not an epidemic would be a misuse of scarce resources. In practice, weekly attack rates of suspect meningitis cases are monitored, and once the epidemic threshold is crossed, the decision to implement a reactive vaccination campaign is made (Anon 2000). To be effective and prevent as many cases as possible, vaccination needs to be implemented quickly. It has been estimated that 60% of the cases could be prevented if vaccination is implemented within four weeks after crossing the epidemic threshold (Moore PS et al. 1992). This time window is extremely short, considering the eventual delay in the flow of surveillance data, the time required to deliver the vaccine and to organize and run the campaign.

Although much debate has been dedicated to the effectiveness of this reactive vaccination strategy, it is widely recognized that there is only a short lead-time for vaccination once an epidemic is underway and the impact of the vaccination response largely depends on the quality and timeliness of the surveillance system. Finally, the characteristics of the polysaccharide vaccine (short duration of the immunity, absence of herd immunity, weakly immunogenic in infants) and its limited availability precludes its use for truly preventive vaccination campaigns (WHO 2007) .

As a consequence of the limitations of the reactive vaccination strategy, a preventive approach involving a conjugate A vaccine has recently been adopted by WHO and its partners. The MenAfriVac™ vaccine, which protects against infection caused by *Neisseria meningitidis* A (Sow et al. 2011); a serogroup which is responsible for the vast majority of the outbreaks, offers great potential to eliminate large meningitis outbreaks as a public health problem (Roberts 2008). Almost 10 years after the initiation of its development by the Meningitis Vaccine Project (MVP, http://www.meningvax.org/), the conjugate A vaccine was successfully introduced in Burkina Faso, Mali and Niger in the last quarter of 2010 and in Nigeria, Chad and Cameroun in 2011 resulting in more than 55 million people vaccinated. A further 5 to 10 years are now required to immunize individuals at highest risk living in the 26 countries targeted by the project. In the meantime, tight epidemiological and microbiological surveillance and forecasting systems which can help identify populations at risk remain a public health priority to detect and respond to meningitis outbreaks (whether due to Nm serogroup A or other that A, such as W135 or X) and to evaluate the impact of the vaccine (Cuevas et al. 2008). In order to better understand the impact of the conjugate vaccine on reducing transmission in Africa, a global research effort led by the African Meningococcal Carriage Consortium 'MenAfriCar', is performing carriage studies in line with the introduction plan of the conjugate vaccine.

While the introduction of the conjugate A vaccine promises to significantly reduce the problem of meningitis epidemics in Africa, the reactive vaccination approach remains an important part of the control strategy for populations not yet immunized with the conjugate A vaccine and in response to epidemics caused by other serogroups such as C, W135 and X.

Climate, environment and the risk of epidemics

There is substantive evidence that climatic and environmental factors describe the overall spatial distribution of the disease in the Meningitis Belt of Africa (Lapeyssonnie 1963) and the indication that climate likely influences the seasonality of the disease is also widely accepted (Greenwood et al. 1985); epidemics start in the latter half of the Sahelian dry season when the weather is dry and dusty and subside at the onset of the rains. Much is still unclear about why they occur but it is likely that a combination of environmental, demographic, and behavioural factors as well as those relating to the hosts' immunity to disease will determine the occurrence of epidemic meningitis. In particular, the fact that the disease incidence tends to fall off rapidly once the moist pre-monsoon air arrives is seen as indicative of an important climatic control to disease occurrence. For a number of years research focused on the relationship of environmental and climatic variables to meningitis incidence produced tantalizing results suggesting a significant interaction (Besancenot et al. 1997; Cheesbrough et al. 1995; Molesworth et al. 2003; Sultan 2005; Sultan et al. 2005; Yaka et al. 2008). However limitations in the data sets and modeling frameworks used precluded a definitive answer (Thomson et al. 2006).

In order to make progress in understanding the relative importance of climate as a driver of meningococcal meningitis epidemics it was deemed necessary to first identify how such knowledge might inform operational decisions under field conditions. After discussions with key policy makers the priority concerns and research questions were identified in relation to 1) improving the reactive strategy with the polysaccharide vaccines in emergency situations in response to epidemics, and 2) supporting the longer-term preventive strategy with the introduction of the new conjugate A vaccine to 300 million people at risk across the Meningitis Belt.

Taking these concerns into consideration, a key identified need was for better data collection and research that could contribute robust estimates of the environmental contribution (alongside other factors such as carriage and immunity) to spatial and seasonal risk, year to year variation and longer term trends in meningitis epidemic occurrence and intensity. The identified research needs according to specific spatial scales and time horizons are elaborated further in the following section and in the table below.

The MERIT Initiative

Converging interests from the health and climate communities around the problem of epidemic meningitis were explored at a meeting hosted by the Group on Earth Observations (GEO) Secretariat in Geneva in 2007. Here a multidisciplinary group of participants (practitioners and researchers from both public health and climate communities) led by the World Health Organization and including the World Meteorological Organization (WMO), the Group of Earth Observations (GEO), the International

Federation of the Red Cross (IFRC), the International Research Institute for Climate and Society (IRI) the Health and Climate Foundation (HCF) and the Agencia Estatal de Meteorología (AEMET) agreed to the creation of the Meningitis Environmental Risk Information Technologies (MERIT, http://merit.hc-foundation.org) project (GEO 2007). A Steering Committee for the initiative was formed the following year in June 2008. In 2011 the Steering Committee was joined by two additional members, one from the National Center of Research Institute/Institute of Research for Development Research Unit in Montpellier, France and the other from the Center for Vaccine Development, CVD-Mali, CNAM, Ministère de la Santé, in Bamako Mali. All current Steering Committee members are authors on this chapter.

MERIT Objectives

The original objectives of MERIT were clearly expressed in the purpose statement for the 1st MERIT meeting which took place at the John Knox Centre in Geneva on 26-27 September, 2007 in relation to advancing a) partnerships b) new knowledge and c) improved decision-making. This purpose stemmed from expressed interests of the public health community to:

1. find a common platform between relevant communities to address meningococcal meningitis epidemics in Africa in the context of perceived environmental, biological, economic and demographic influences;
2. gain a greater understanding of the current knowledge and active research surrounding the epidemic risk indicators; and
3. communicate the information needs of the public health community to the research community to enhance epidemic meningitis control strategies in Africa.

The MERIT Initiative was designed to encourage greater cross-disciplinary interactions, connect research more directly to the needs of public health practitioners and provide a unique model for building effective health-climate partnerships within the framework of improving health outcomes. The specific objective of the Steering Committee was that of charting the course of the MERIT consortium throughout its expected lifetime of a decade. The consortium aims to extend current capabilities to more effectively combine environmental information with knowledge of epidemic meningococcal meningitis through analysis of the spatial and temporal distribution of cases, populations, environmental and climatic conditions, vaccination status and strain characteristics. Ultimately, this research seeks to inform three operational areas:

1. the reactive vaccination strategy (improve the impact of the reactive mass vaccination campaigns), prepare for the following epidemic season, and refine the response strategy for outbreaks due to serogroups other than A;
2. the preventive vaccination campaigns with the conjugate A vaccine (guide the introduction of the conjugate A vaccine and estimate the impact of the conjugate A vaccine); and
3. 5 to 10 years time-horizon forecasting to gather information on the possible vaccine needs in the medium and long term.

Despite much progress in surveillance and biological research in recent years, no explanation exists to date for the epidemic pattern of meningitis in the African Meningitis Belt (Mueller; Gessner 2010). Hence MERIT has tried to stimulate and support modeling efforts that might better explain the epidemic pattern of meningitis across the Belt as well as identify opportunities for prediction.

Key to the MERIT concept was consensus among partners that research needs would be demand-led, ie. identified by those that were responsible for solving the health problem. Taking this approach, MERIT seeks to serve WHO, Ministries of Health, the Meningitis Vaccine Project and other relevant research initiatives such as MenAfriCar in the prevention and control of meningitis epidemics in Africa.

While the development and refinement of research questions are guided by the public health needs, the momentum of the MERIT Initiative is in large part sustained by long-term research grants which support specific research questions, often over a period of several years. The challenge that has arisen is to determine how to maintain a degree of flexibility in the research arena in such a way that enables the research projects to stay in line with a changing public health strategy.

Summary table of analysis scale and research needs identified by WHO

Research need	Spatial scale	Time scale
To improve the impact of the reactive mass vaccination campaigns	District	Forecast the weekly attack rate several weeks ahead of time
To prepare for the following epidemic season	Region, country	Forecast the magnitude of an epidemic (yearly cumulative rate) one year ahead of time
To refine the response strategy for outbreaks due to serogroups other than A (NmW135, NmX)	District	Forecast the weekly attack rate several weeks ahead of time
To assess the risk of NmA outbreak in an area previously vaccinated with the conjugate A vaccine	District	Forecast the weekly attack rate several weeks ahead of time
To guide the introduction of the conjugate A vaccine	Region, country, district	Seasonal risk and historical trends
To estimate the impact of the conjugate A vaccine	Region, country, district	Predict the number and magnitude of epidemics one/several year(s) ahead of time
To gather information on the possible vaccine needs in the medium and long term	Region, country	Predict changes in the meningitis belt 5-10 years ahead of time

MERIT Research Networking Capabilities

In its initial phase the MERIT consortium has focused on core countries of the Meningitis Belt (including Niger, Burkina Faso, Ethiopia, Ghana, and Nigeria). Four international technical meetings have been held in Geneva (2007), Ethiopia (2008 and 2010) and Niger (2009), gathering over 30 research and practice groups from the public health and environmental sectors, governments, regional and international organizations as well as research institutions. Over 100 research papers have been presented in oral or poster format. Smaller 'Mini MERIT' meetings have been held in New York (USA), Montpellier (France), Lancaster (UK) and Boulder (USA) and have focused on specific research modeling questions. Presentations and MERIT meeting reports have been made available on the web via http://merit.hc-foundation.org. MERIT members are in the process of publishing their results in peer review journals.

Research groups from Europe, the USA and Africa have attended each of the technical meetings. Despite these meetings occurring in Ethiopia and Niger, participation by African research groups has been limited; at least in part because funding for MERIT has been largely based on 'contributions in kind' to MERIT participants and the bringing together of ongoing research efforts. However, African, European and American scientists and decision-makers involved in MERIT have benefited from participation in the MERIT meetings and also in ancillary activities such as the IRI Summer Institute 'Climate Information for Public Health'.

Summary of Research projects performed under the MERIT umbrella or relevant for MERIT

As a research consortium without core funds MERIT achievements are in reality the achievements of MERIT members some of which have developed and implemented specific MERIT related research projects, others of which have contributed research efforts developed under another umbrella to the overall MERIT initiative. Research outputs are ongoing and results to date were formally reviewed at an International Technical meeting in Geneva in November 2011. Information on the partner institutions and engagement in MERIT related activities at the international, regional and country levels can be found on the MERIT website (http://merit.hc.foundation.org). Details on key institutional contributions are indicated below:

International research and initiatives

World Health Organization (WHO): Central to the work of MERIT and guiding the research projects are the operational activities of WHO country, regional and international teams.

WHO provides technical assistance and support to Ministries of Health to help improve the prevention and control of meningitis epidemics in the region. The WHO office in Geneva responsible for meningitis control is within the Pandemic and Epidemic Diseases (PED) Department and works closely with the WHO African Regional Office Intercountry Support Team based in Ouagadougou, Burkina Faso to strengthen data management and surveillance of meningitis across the Meningitis Belt countries. As seen in recent years, the unpredictable nature of the extent and intensity of meningitis epidemics and the changing influence of meningococcal strains from one year to the next, emphasize the importance of robust meningitis surveillance across the Meningitis Belt. Furthermore, in its role as Secretariat of the International Coordinating Group (ICG) for Meningitis Vaccine Provision, WHO is responsible for the management of the global emergency vaccine stockpile funded by the GAVI Alliance and works closely with other ICG partners (UNICEF, Médecins Sans Frontières and the International Federation of the Red Cross), vaccine manufacturers and Member States to ensure a rapid response to meningitis outbreaks.

Within the MERIT framework, WHO has helped guide the design of research projects with a view to integrating the increasing understanding of environmental influences on meningitis epidemics into the meningitis control strategy. Ultimately, WHO would like to synthesize research outcomes from various MERIT projects in such a way as to support its activities in the field and strengthen the decision algorithm which determines the timing and distribution of vaccines to countries during an epidemic season.

The engagement of WHO with MERIT partners has initiated several new areas of activity, including:

1. Chairing the MERIT Steering Committee and facilitating the interactions between MERIT partners through annual technical meetings. Since 2007, these international meetings have been held in Geneva, Addis Ababa, Ethiopia and Niamey, Niger. Smaller 'mini-MERIT' meetings have been held on an ad hoc basis in order to engage public health specialists with research groups to present outcomes and review the direction of specific research projects.

2. WHO has recently led the development of a district prioritization tool (DPT) to support the roll-out of the new conjugate A vaccine in countries and districts across the Meningitis Belt. This tool is at the heart of the current public health vaccination strategy and integrates factors such as vaccine availability, current epidemiology, country capacities for implementation and surveillance, and political situations. While the DPT tool is not a result of the MERIT project, there is potential for results from MERIT research activities to feed into the tool and inform the strategy for the introduction of the conjugate A vaccine.

3. Participation with research scientists, developers of predictive models and disease focal points in several countries of the Meningitis Belt (see below) in cross-sectoral monitoring exercises of the 2010 and 2012 meningitis epidemic seasons.

The **CHICAS (**Combining Health Information, Computation and Statistics) **research group** at Lancaster University has invested in the development of several spatio-temporal models designed to support national- and district-level short-term forecasting of meningitis epidemics. The project has advanced through collaboration between Lancaster University and Columbia University's International Research Institute for Climate and Society (IRI). Combining weekly epidemiological data from Niger (1986-2007) with gridded reanalysis climate data for the region aggregated to the national level including humidity, temperature dust and wind, the preliminary results suggest that climate data is of limited value for short-term (sub-seasonal) forecasting but would add value to longer-term forecasting of the meningitis season ahead. While plans to field-test one of the models in Niger in early 2011 were abandoned due to the political situation at the time, the group is engaged in an exercise with WHO in Geneva, Togo, Benin, Chad and Nigeria to assess on a weekly basis the predictive output of the models during the 2012 meningitis season. At the end of the season, a formal analysis will be held to assess the performance of three different types of models (Markov, Dynamic Linear Model and Dynamic Poisson-log-linear) in line with the actual epidemic activity during 2012.

Integrated Geophysical Modeling for Regional Climate Studies- the South East European Virtual Climate Change Center (SEEVCCC) hosted by the Republic Hydrometeorological Service of Serbia is developing a regional Earth modelling system with a dust component integrated to perform subseasonal/seasonal/climate studies. With the global database on mineral in arid soils, SEEVCCC should contribute to MERIT by assessing environmental conditions (dusty weather; mineral composition of dust) on time scales longer than current 2-3 days.

International Research Institute for Climate and Society (IRI), the Earth Institute, Columbia University: The IRI has been active in the MERIT initiative since its inception through support to the Steering

Committee, the International Meetings and as host to New York based 'mini-MERIT' meetings contributing its scientific and technical capacity in the area of climate information for public health. Along with partners at Columbia University (the Center for International Earth Science Information Network (CIESIN), Goddard Institute of Space Studies (GISS) and Mailman School of Public Health) it has led several research projects under the MERIT framework to advance the understanding of the environmental factors (climate and aerosols) and population dynamics as determinants of meningitis epidemics in the Meningitis Belt. These include projects focused on the development of ground observations, remote sensing products and model outputs (including seasonal climate predictands) of direct relevance to modeling the climate and environmental drivers of meningococcal meningitis. In collaboration with other research and operational groups within MERIT the IRI engaged in projects with funding from NOAA, NIEHS, NASA and Google.org to help improve the application of available information and knowledge on the factors which influence meningitis epidemics, with a view to improving decision-making in meningitis control. The IRI has also contributed to the MERIT initiative through its innovative Summer Institute 'Climate information for Public Health' and has enabled the public distribution of relevant data sets through the IRI Data Library meningitis maproom (Figure 1).

MACC - Monitoring Atmospheric Composition and Climate - is the current pre-operational atmospheric service of the European GMES programme (http://www.gmes-atmosphere.eu/). MACC provides data records on atmospheric composition for recent years, data for monitoring present conditions and forecasts of the distribution of key constituents for a few days ahead. MACC WP 3.1 (funded by the EU and NSF Spain) "Meningitis linked to mineral dust transport in the Sahel", a collaborative project between the Meteorological State Agency of Spain (AEMET), The Earth Institute at Columbia University (IRI and NASA-GISS), the Barcelona Supercomputing Center (BSC-CNS) and the Spanish National Research Council (IDAEA-CSIC) has provided detailed validation of the dust model in the Sahel and elsewhere (Cuevas et al. 2011).

MAMEMA - Multidisciplinary Approach for Meningitis Epidemiology and Modeling in Africa: a consortium of MERIT partners was formed in 2010 to help increase the sharing of information between research groups on projects related to meningitis transmission dynamics and modeling in the Meningitis Belt. The initial areas of focus of the group under the MERIT framework concern the identification and the estimations of key parameters that should be included in epidemiological models based on the current knowledge and data availability. Another aspect is to define the future projects that could provide crucial parameters estimations for the models under development. The group gathers researchers from different complementary disciplines included epidemiology, medicine, public health, immunology, epidemiological modeling, climatology, anthropology and biostatistics). A first meeting occurred in Montpellier in 2011 and several kinds of models were presented to improve the reactive (see DTP presented above) and the preventive vaccination strategies(Irving et al. 2011). A second meeting was held in April 2012 in Montpellier. Presentations focused on the identification and estimation of environmental, climatic, epidemiological and societal parameters relevant for epidemiological modeling, to inform the long term vaccination strategies at different spatial scales (health center, districts, national) (Bharti et al. 2011; Irving et al. 2011; Paireau et al. 2011).

The MAMEMA consortium aims to understand the drivers of localized epidemics and includes research partners from CNRS/IRD - France, University of Bourgogne, Princeton University, Penn State University, University of Bristol, Washington state University, Agence de Médecine Préventive (AMP), Lancaster University, and Ecole des Hautes Etudes en Santé Publique (EHESP), Paris and is connected with MenAfriCar.

UCAR Project: The University Corporation for Atmospheric Research (UCAR) in Boulder, Colorado USA received funding from Google to research methodologies for short-term forecasting during the meningitis season, with initial emphasis on the end of the meningitis season. Building on the historical work of the Navrongo Health Research Centre in Ghana and working with North Carolina State University, Regional Maritime University in Ghana and the IRI, the project aims to help increase the understanding of environmental variables which may influence the epidemic status of a district, and use that information to better respond to epidemics already in progress or about to start. Using a differential-equation based model of disease transmission, physical insight into meningitis transmission, 10 years of regional data and 2 years of data from across the Belt, the team was able to show that humidity, NE winds and heat all show positive correlations with future cases, as compared to historical persistence. An additional test with a generalized additive model confirmed that the temperature, humidity, and carbon monoxide concentration (as a proxy for burning) were the variables most persistently related to meningitis. These two models, along with current epidemiological data and weather forecasts, provide the basis for weekly predictions of meningitis cases that can help guide vaccination. Other areas of research include determining the economic benefits of the forecast, surveying to document the knowledge, attitudes and practices of area residents, identifying the impacts of these predictions and other public health interventions and, most importantly, developing an information system for surveillance, data collection and disease management.

WMO Sand and Dust Storm Warning System

Of particular relevance to the MERIT project has been the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) which was developed to study, among other questions, the impacts of dust aerosol on health, including the possible link of dust with meningitis and other diseases. The initial premise being that the prediction of dust events can help to better understand the hypothesized role of mineral dust and dry hot air in outbreaks of meningitis across the Meningitis Belt in the Sahel region. Under the SDS-WAS umbrella there are several activities and studies of relevance for MERIT; some of which have been specifically undertaken to support the MERIT initiative. For instance, in 2010 a SDS-WAS regional centre for Northern Africa, Middle East and Europe established a “one-stop-shop” portal (http://sds-was.aemet.es/) which delivers near-real-time observations and short-medium range forecasts of dust-related parameters as well as forecasts of associated meteorological conditions.

SDS-WAS observations and products include:

1) Ground observations:
2) Satellite products:
3) Dust forecast products for periods of several days ahead combining information available from several organizations which run dust modelling systems.

The parameters of potential importance for MERIT include:

a) columnar dust amount,
b) surface concentration,
c) wet and dry deposition.

Of notable significance is the fact that, since the dust concentration component in numerical models is driven by the atmospheric model, meteorological values such as temperature, air moisture, wind and precipitation are available simultaneously with the dust-related parameters (Nickovic et al. 2011). All data mentioned above are available on a daily basis for the Meningitis Belt and beyond and can now be accessed via the IRI Data Library (iridl.**ldeo**.columbia.edu/ see Figure 1) as well as from their original source.

Country-led MERIT initiatives:

MERIT partners in disease endemic countries have formed local consortia with an aim to apply MERIT research outputs into operational decision-making at the country level as outlined below. While the importance of supporting country-led activities is well recognized by the MERIT community, it is critical that additional resources are allocated to ensure the development and application of research projects targeted to country-specific needs while helping build capacity in countries to sustain the activities.

Burkina Faso

In Burkina Faso the National Meteorological Services has run an "Environment and Bioclimatology" desk for the last ten years in order to a) promote research on the relationship between climate - environment and diseases distribution – emergence, b) to use observations forecasts and information on environment and climate to predict diseases outbreak and spatial distribution and c) to contribute to elaboration of an integrate early warning system for prediction of climate sensitive diseases and promotion of suitable public health policies.

Among others activities, at the beginning of the meningitis epidemic season every year, a joint bulletin from National Meteorological and Health Services on prediction of meningococcal meningitis yearly incidence trend in Burkina Faso and Niger is produced by integrating climate, environment and health data and information. At the end of the year, a common evaluation is done. This information is jointly transmitted to national, regional and international organization and research centers working in medical and climate sectors as a contribution to help mitigate the diverse consequences of meningococcal meningitis epidemics. Using reanalysis data from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) reanalysis project (with an up-to-date version of the Medium Range Forecast model) statistical analysis of annual incidence of meningococcal meningitis and climatic variables for Niger indicated that 25% of the disease variance from year-to-year in this country can be explained by the winter climate; a similar analysis failed to represent accurately the disease dynamics in Burkina Faso (Yaka et al. 2008).

Ethiopia

Following the 2nd MERIT Technical Meeting in Addis Ababa in 2008 (MERIT 2008), the 'MERIT Ethiopia' project was established to help apply MERIT research across four key operational areas: 1) socio-economic impact of the disease, 2) determinants and risk factors of meningitis outbreaks, 3) education and training, and 4) disease surveillance. The MERIT-Ethiopia project was expected to benefit from and leverage the high level political momentum which had been generated by the formalization of a collaborative framework between the health and climate sectors under the title 'Climate and Health Working Group'. Despite this initial optimism however, the engagement of donors to support the country-led activities has not been actively pursued at the country level or by the MERIT Steering Committee, and as such the potential results have not yet been realized.

Niger

Niger is historically one of the most active countries in the Meningitis Belt in terms of epidemic activity and has one of the strongest epidemiological databases in the region over the past 20 years. In November 2009, the 3rd International MERIT Technical meeting (MERIT 2009) was hosted by the African Centre for Meteorological Applications for Development (ACMAD) and the Centre de Recherche Médicale et Sanitaire (CERMES) in Niamey, Niger. The meeting was followed by a one-day national training workshop which provided an opportunity for national meteorological staff, health practitioners and medical students to engage with local MERIT partners and assess the benefits and applications of MERIT-related activities in Niger.

In relation to the MERIT objectives, the Centre de Recherche Médicale et Sanitaire (CERMES – a national medical research laboratory in Niger that is part of the Institute Pasteur Network) is leading a project entitled "Spatial epidemiology of acute bacterial meningitis in Niger. Role of climatic, environmental, health and socio-demographic factors on the spatio-temporal dynamic of the epidemics" in collaboration with Institut Pasteur in Paris (Emerging Diseases Epidemiology' Research Unit). The three-year project is financed by the Coopération Monégasque for the period October 2010 to September 2013. The project consists of three components: 1) a descriptive study which aims to detect clusters of meningitis cases during the meningitis epidemic seasons generally occurring from February to April each year; 2) an ecological and geographical study of the role of the climatic, environmental, health and socio-demographic factors on the occurrence of meningitis epidemics and to build a risk map for meningitis epidemics; and 3) to build an early warning system to help decision-making in relation to the implementation of reactive vaccination campaigns.

Other activities led by CERMES which consider the link between the climatic factors and the occurrence of meningitis are based on the use of time series studies and incorporate other risk factors such as respiratory infections. A first study has been conducted in the Niamey area whereby a generalised additive model was used to relate the daily change in bacterial meningitis cases and climatic factors. First results were presented at the Hong Kong International Tropical Medicine Forum in January 2012.

Nigeria

In Nigeria, a state level MERIT committee was established in Katsina State bordering Niger in northern Nigeria. With an initial level of financial support provided by the State Focal Office on MDGs in the Governor's Office, the 'MERIT Katsina' project aims to: 1) fully realize current meningitis research and development initiatives, 2) build capacity within health and climate community to improve health outcomes in the state, and 3) identify gaps and accelerate new warning and intervention strategies for meningitis. The MERIT Katsina group has also initiated a strong collaboration with the MAMEMA consortium**.**

Regional MERIT initiatives across the Meningitis Belt:

ACMAD – African Centre of Meteorological Application for Development

Based in Niamey, Niger, ACMAD was instrumental in the organization of the 3rd MERIT meeting held in November 2009. The Centre produces a weekly 'Special Climate-Health Outlook Bulletin' to help translate meteorological observations and forecasts into a more meaningful language for the meningitis public health community. The bulletin is distributed on a weekly basis throughout the meningitis season and highlights: 1) the observed climate situation across the region for the previous two weeks, 2) the epidemiological situation based on weekly updates from the WHO Inter-country Support Team (IST) West Africa office in Ouagadougou, Burkina Faso, and 3) the climate outlook for the next week based on NCEP/NCAR, NOAA/NCEP/CPC and BSC-DREAM8b models. According to the observed and forecast climatic parameters (relative humidity, temperature and dust events), potential meningitis risk zones are identified with a view to informing the decisions of public health practitioners in relation to meningitis outbreaks in the region.

"Following the Season: 2010"

Following the 3rd MERIT meeting held in Niamey, Niger in November 2009, a cross-sectoral monitoring of the 2010 meningitis epidemic season was initiated. Throughout the 2010 meningitis epidemic season, WHO participated in an exploratory exercise with the IRI and the African Center of Meteorological Applications for Development (ACMAD) to follow the meteorological and epidemiological developments of a meningitis season. Between December 2009 and April 2010, WHO (Geneva, Switzerland), ACMAD (Niamey, Niger) and the IRI (New York, USA) met via teleconference on a 10-daily basis to share information on 1) the developments of epidemic outbreaks in districts and areas of alert across the Meningitis Belt, and 2) the climatic, meteorological and air quality observations and forecasts at the global and regional level. Climate information discussed global Sea Surface Temperature anomalies (known to influence atmospheric circulation on seasonal time-scales), large scale atmospheric circulation indices such as NAO (past and projected conditions) relevant for dust bearing circulation patterns, information on recent wind and humidity conditions including the location of the Inter-tropical Discontinuity (ITD-a region of convergence between the dry and dusty air from the Sahara and moist and dust-free air from the Atlantic) as well as on dust (past conditions and 8-day forecasts).

In total, 12 teleconference calls were held over the four-month period, and while anecdotal feedback has been recorded a formal assessment of the exercise is yet to be finalized. Throughout the season observed climate showed conditions not favoring meningitis outbreaks with frequent higher than usual

humidity, lower wind and dustiness conditions, consistent with a relatively quiet meningitis season until mid-March.

Retrospective analyses of the 2009 and 2010 seasons showed that, while epidemic behaviour differed substantially between those years, climatic conditions averaged over the entire season did not exhibit such substantial differences. However, when analysed at the in sub-seasonal scale, climatic characteristics were found to differ between years: in 2010 higher variations in low level wind and humidity patterns brought moist and dust-free air to the region more often than in 2009, except in Burkina Faso, where the higher sub-seasonal variability in wind patterns translated in higher occurrence of dry and dusty episodes in 2010 as compared to 2009 (Trzaska et al. 2010). This points to the potential importance of sub-seasonal characteristics of the season in meningitis outbreaks but needs to be further documented.

"Outbreak prediction tool: tested in real time in Season: 2012"

Building on the experience of the 2010 exercise outlined above and following the recommendations from the MERIT Strategic Review in 2011, WHO is leading an exercise to prospectively assess the output of several statistical models developed to provide sub-seasonal, district-level predictions of epidemic activity (Agier et al. 2012; Stanton et al. 2012) alongside the observed incidence of cases and epidemics during the 2012 meningitis season (January – May 2012). With a focus on Togo, Benin, Chad and Nigeria, disease experts and focal points from WHO (Geneva, African Regional Office and Country Offices) engage on a weekly basis with the developers of the models from the CHICAS group at Lancaster University and climate science researchers from UCAR and NASA GISS (Columbia University).

The purpose of the exercise is to assess the performance of statistical models tailored for predicting meningitis epidemics with a lead-time of one to four weeks, alongside the observed epidemic behaviour in the Meningitis Belt. The observed and forecast relative humidity and dust events in the region are integrated into the discussions in order to consider the environmental conditions favourable for epidemics. A formal analysis of the exercise will be conducted at the end of the season to determine the performance of the models and their utility to support the ongoing public health strategy and preparation of vaccination campaigns in the region.

Of particular interest in 2012 as compared to the previous two years, is the relatively high level of epidemic activity due to serogroup W135 and low activity due to serogroup A. This could be an area of further investigation, incorporating the results of the two seasonal exercises from 2010 and 2012 with microbiological, immunological, epidemiological, environmental and vaccination data from the past few years.

Bringing it all together

Through the MERIT initiative a much broader understanding by natural scientists of the problem of epidemic meningitis in the Sahel has been achieved. GEO, AEMET and WMO have played a significant role in ensuring that policy makers in the environmental community are aware of MERIT and have sought their support through its network of high-level partnerships.

Disparate data sets have been enhanced and brought together for analysis. These include epidemiological data sets from national surveillance systems facilitated through WHO, population data from the Global Rural-Urban Mapping Project (GRUMP) from CIESIN (at Columbia University) and a wide range of environmental and climatic variables now made available via open access portals such as the IRI Data Library. The challenge of integrating these disparate datasets should not be underestimated. Combined with practical knowledge of the data sources and their constraints a raft of modeling exercises have been undertaken by the different research teams. In countries such as Niger where meaningful information can be extracted from large historical databases, statistical analyses such as those based on based on a Bayesian network approach (Beresniak et al. 2012) or geo-spatial analysis (Stanton et al. 2011) have demonstrated that innovative techniques can be developed to help understand and predict the risk of meningitis outbreaks at the district and sub-district level. This modeling effort has been combined with detailed field studies in some countries, such as those at Navrongo, Northern Ghana (Vanja Dukĭc et al. in press).

More recently models which can incorporate both extrinsic (e.g climate/environmental) and intrinsic (e.g. immunity) drivers have been explored.

Possible role of dust mineral composition in meningitis epidemics

The mechanism by which dust may cause meningitis epidemics remains unclear. A common explanation is that physical damage to the nose and throat epithelial cells by dust particles permits invasion of bacteria into the blood stream. It is hypothesised that the activation of the meningococcal bacteria is fostered with high iron content in Fe-rich minerals in dust (Thomson et al. 2009). Current dust models are not capable of simulating/predicting in details the mineral fractions and trace metals such as Fe in dust concentration. However, recently developed global high-resolution (1-km) datasets on soil mineralogical composition (Nickovic et al. 2012) if used as input in dust models could help better understand the possible links between meningitis and iron fraction in dust.

Limitations of current modelling studies and environmental products

Most of the products relevant for MERIT are publicly available. However, short-term forecasts have limited value for MERIT because, in the case of operational dust modelling, forecasts are valid for 3-5 days in advance which is too short a period to be of practical use for planning vaccination actions in the field. On the other hand, observational data (including remote sensing products) and re-analyses made for multi-decadal periods can help understanding if and how meningitis outbreaks depend on environmental conditions and their seasonality.

Medium range sub-seasonal forecasts may prove relevant for MERIT with promising opportunities for designing such concepts. Several operational centers (including the European Centre for Medium-Range Weather Forecasts (ECMWF), UK Met Office, Japan Meteorological Agency (JMA), US National Centers for Environmental Prediction (NCEP), Environment Canada and the Bureau of Meteorology in Australia) are already providing global experimental sub-seasonal/seasonal forecasts. Several other organizations such as UCAR are also working on predictions for the same time scales while using regional modelling facilities. Following interest for such forecasts over extended periods, WMO (as a joint WCRP and WWRP initiative) is currently launching a new project “Sub-seasonal to Seasonal Prediction”. With additional

dust components in such systems, it will be possible to explore the value of longer-term dust forecasts for the needs of the MERIT health community.

Contributions from the MERIT climate community to the assessment of the links between weather/climate and meningitis occurrence

A number of significant modelling results are emerging from different research teams as a result of the creation of new sources of weather, climate and environmental data tailored to MERIT needs. For example a series of analyses have resulted through the development of the dust-modelling activities of the SDS-WAS.

In a study based on a 30-year simulation model (1979-2010) recently developed with a 0.5º x 0.5º resolution (NASA-GISS, IRI, BSC) (Perez et al. 2011) the relation between meningitis outbreaks in sub-Saharan Africa and simulated dust aerosol concentrations over the Meningitis Belt has been examined (Perez 2008). The study concludes that there is a certain level of correlation between dust and climate variability parameters, such as the NAO index. This result forms a basis to use climate indices as first-approximation indicators on favorable conditions for meningitis outbreaks.

Using the same simulation model (NASA-GISS, IRI, BSC, CHICAS) the relation between meningitis outbreaks in sub-Saharan Africa and simulated dust aerosol concentrations over the Meningitis Belt has been examined. The outputs of the simulations have been validated at the daily, seasonal, annual, inter-annual and trend scales using in situ and satellite dust data (Perez et al. 2011; Haustein et al. 2012). They are also being used to perform a seasonal and weekly analysis of meningitis epidemic outbreaks at national and district levels in Niger (Stanton et al. 2011; Perez, 2012).

Preliminary results show that climate parameters (including wind and dust) prior to January and early season meningitis cases explain about a quarter of the epidemic year-to-year variability at national and district level At the district level, both national-level covariates and district-level covariates of climate and dust variables and early cases together with population density and latitude represent moderately well the spatio-temporal variability of the diseases. Although the study outlines the need for other sources of data to better represent between-district variability (susceptibility, viral infections, new strains or previous vaccinations), the study shows the potential of climate information in the early season to explain part of the variability of the disease at the seasonal and district scale (Stanton 2012). Another study under progress in the framework of the MAMEMA group shows that aerosols represent a relevant climate and environmental parameter (together with wind, relative humidity and temperature) to explain the seasonal pattern of meningitis at the district level in Niger.

The non-linear interaction of different co-factors, many of them not known, partly hampers the assessment of the impact of climate and dust upon epidemics. This problem is even more critical at the weekly scale. In a recent study using the regional dust and climate database (Stanton et al. 2011), at the national scale, zonal wind and dust concentration made modest improvements in meningitis incidence forecasting ability, but the majority of temporal variation could be explained using a seasonal trend and previous incidence. At the district level, the inclusion of climate variables made no real difference to the

forecasting performance of the models and the majority of temporal variation could be explained using a seasonal cycle and previous incidence (Stanton et al. 2011).

Data policy challenges and opportunities

The MERIT Steering Committee has sought to create a data policy designed to achieve maximum research opportunities and outcomes while promoting open use by Health practitioners and decision makers for the public benefit. However no single solution has been found to the diverse types of data involved and the diverse needs of the MERIT community since different data and products carry different access and dissemination conditions (eg restrictions due to privacy) and intellectual property rights. As a consequence the MERIT Steering Committee is actively discussing data sharing through the WHO information platform OpenHealth, the IRI Data Library and the GEO WebPortal (http://www.earthobservations.org). The IRI Data Library is making MERIT related environmental and climate data available to the global research community.

The 4th MERIT Technical Meeting in Addis Ababa, Ethiopia (MERIT 2010) extensively discussed the issue of data sharing, interoperability and developments of tools, including a proposal of a central MERIT information system. While so far the MERIT information systems are a combination of independently developed information systems, the community is continuing to explore technical options in order to realize the MERIT goals.

Meningitis Map Room

The Meningitis Map Room, situated in the IRI Data Library, makes Meningitis-related environmental, demographic, and epidemiological data available for visualization, integration, analysis, and download (http://iridl.ldeo.columbia.edu/maproom/.Health/.Regional/.Africa/.Meningitis/). The data are web-accessible through a set of easy-to-use map pages and links to datasets. The spatial extent of the area of interest is controlled by click and drag cursor controls. First and second order administrative boundaries are used to calculate time varying spatial averages of gridded environmental data. These environmental time series can be correlated with time series of epidemiological data or downloaded to the user's desktop. New datasets are added when the spatial resolution or quality of the data is an improvement upon existing map room datasets (Figure 1).

The environmental data include rainfall, temperature, relative humidity, visibility, and wind speed. There are environmental quantities from a regional dust model run that spans 1979-2008. The demographic data is the CIESIN Gridded Population of the World Version 3 (GPW3).

MERIT today and future direction

The 5th MERIT Technical Meeting and strategic review took place in Geneva, Switzerland in November 2011. At this meeting the achievements of MERIT to date were evaluated by an independent group of experts and a new chart for MERIT activities was developed based on the changing needs of the

meningitis control community. Key outcomes from this meeting and highlights of the preliminary research results are outlined as follows.

1) **New evidence has been produced on the contribution that climate and environment make to the spatio-temporal distribution of meningococcal meningitis.**
   a) Meningitis – climate/environment linkages have been further elaborated using robust statistical techniques taking into account the natural history of the disease, non-climatic factors and verified and relevant climate and environmental information. However the lack of understanding of the mechanisms and the interaction of infection, disease and immunity remains a challenge to the interpretation of these results.

2) **Transitioning research into policy and practice is strengthened by a strategic approach for the creation of evidence, together with the development of a cumulative knowledge base.**
   a) The multi-sectoral steering committee, led by WHO, enables new communities to be bought together that are focused on policy-relevant problem-focused research.
   b) The creation of mini-MERIT meetings has enabled highly focused scientific discussions to be developed and shared.
   c) The increased profile of meningitis as a climate sensitive disease has created funding opportunities for researchers.

3) **An effective means for the dissemination of new knowledge together with development of means to broadly access this knowledge has been undertaken.**
   a) MERIT international meetings provide a platform for sharing new data, research innovation and scientific knowledge.
   b) Peer review publications and presentations at scientific and policy conferences/workshops have been used to disseminate research findings.
   c) Engagement with national research and health decision-making partners has enabled learning and dialogue between south-south-north MERIT partners.
   d) The development of a MERIT website http://www.merit.hc-foundation.org has enabled widespread sharing of MERIT information.

4) **Initiatives to increase the uptake of evidence in both policy and practice are in development.**
   a) As data and learning accumulate, the opportunity to engage new partners with a move to a multi-disease approach is opening up new operational research opportunities.
   b) MERIT responsiveness to changes in policy environment – i.e. the move from a reactive to preventive vaccine strategy has resulted in prioritization of longer term changes in the Belt.
   c) Creation of training opportunities such as the IRI Summer Institute 'Climate Information for Public Health Action' has increased understanding of researchers and decision-makers in use of climate information.

The strategic review and technical meeting succeeded in large part by engaging both MERIT partners who have been actively involved in the Initiative to date and a small group of independent, external

advisers representing the areas of meningitis control, environmental information and policy makers. Technical partners provided updates on latest research activities and preliminary outputs were discussed extensively in light of the current public health priority areas. The advisory group acknowledged the high commitment and quality of the multi-disciplinary teams involved in MERIT, as well as the willingness to adapt and streamline their research in line with the changing public health situation. Recognizing the importance and relevance of preliminary research results, the advisory group highlighted the need to translate new knowledge into operational activities in order to lead to tangible public health impacts and improved decisions.

As a result of the strategic review, consensus was reached on the importance for MERIT to continue with clarification of priority research needs in light of a changing epidemiological landscape and renewed focus on translating new knowledge into decisions and operations. The MERIT Steering Committee is reviewing the structural and financial needs of the Initiative to ensure its future sustainability and to support MERIT activities in countries of the Meningitis Belt.

The collaborative partnership model that the MERIT initiative has demonstrated over the past five years provides a promising, innovative framework to support public health preparedness and control strategies. MERIT's strength is that the research conducted has been driven in large part by clearly articulated public health questions. Public health decision-makers have been willing to explore unfamiliar territory and opportunities for improving well-established control strategies by leveraging new knowledge and expertise from the climate, environmental and research sectors. Equally important have been the investments made by the scientific and practice communities across various disciplines to adapt research projects in line with the evolving public health strategy across the Meningitis Belt. Not limited to the problem of meningitis epidemics in Africa, the lessons learned from the MERIT initiative offer valuable input and new ideas for improving global public health strategies for other climate/environmentally sensitive epidemic prone diseases of international concern.

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