

DIMACS Center
Rutgers University

US-Africa Advanced Study Institute of Mathematical Modeling of
Infectious Diseases in South Africa
Cape Town, South Africa

Annual Report

August 2007

Participants who spent 160 hours or more

PI: Fred Roberts, DIMACS
Brenda Latka, DIMACS

Other Participants:**US-Africa Advanced Study Institute on Mathematical Modeling of Infectious Diseases in Africa**

June 11 - 22, 2007

Organizers:

Brenda Latka, (Program Chair), DIMACS
Wayne Getz, UC Berkeley
Abba Gumel, University of Manitoba
Fritz Hahne, AIMS
John Hargrove, SACEMA
Simon Levin, Princeton University
Edward Lungu, University of Botswana
Fred Roberts, DIMACS
Alex Welte, Wits University

Lecturers:

Jonathan Dushoff, Princeton University
Wayne Getz, University of California, Berkeley
Abba Gumel, University of Manitoba
Suzanne Lenhart, University of Tennessee
James Lloyd-Smith, Penn State University
Edward Lungu, University of Botswana

Special Lecturers:

Martin Meltzer, CDC Atlanta
Fred Roberts, DIMACS

US Participants:

Shweta Bansal, University of Texas, Austin
Steven Bellan, UC Berkeley
Ashley Crump, Howard University
Lily Davidoff, NJIT
Dylan George, Colorado State University
Moses Haimbodi, Lincoln University
Chris Langhammer, Rutgers University
Devroy McFarlane, Howard University
Akongnwi Mformbele, Lehigh University
Sean Moore, Oregon State University
Anthony Ogbuka, Morgan State University
Anike Oliver, Howard University
Camisha Parker, Virginia State
Alex Perkins, University of California, Davis

Sarah Radke, University of North Carolina
 Danielle Robbins, Arizona State University
 Sourya Shrestha, University of Michigan
 Althea Smith, North Carolina State
 Evelyn Thomas, Howard University
 Alicia Urdapilleta, Arizona State University
 Holly Vuong, Rutgers University
 Nakeya Williams, Morgan State University

South African Participants:

Folashade Augusto, Federal University of Technology Akure, Nigeria
 Ilyes Boulkaibet, AIMS
 Ibrahim Elmojtaba, University of Khartoum, Sudan
 Azamed Gezahagne, Addis Ababa University, Ethiopia
 Margaret M. Kajotoni, AIMS
 Angelina M. Lutambi, AIMS
 Matadi Maba, University of Kwa-Zulu Natal, South Africa
 Gesham Magombedze, National University of Science and Technology, Zimbabwe
 Gilbert Makanda, University of Zimbabwe
 Theresia Marijani, University of Stellenbosch
 Zindoga Mukandavire, National University of Science and Technology, Zimbabwe
 Thembile Mzolo, University of Kwa Zulu Natal
 Samuel Nartey, AIMS
 Victoria Nwosu, AIMS
 Joy Okonkivo, AIMS
 Daniel Okuonghae, University of Benin, Nigeria
 Lois Olatayo, AIMS
 Ndubuisi Omaghali, AIMS
 Tinevimbo Shiri, University of Witwatersrand
 Thibaut Zajack Takadong, University of Witwatersrand
 Kyle Tomlinson, University of Kwa Zulu Natal
 Selamawit Woldesenbet, University of Western Cape
 Azamed Yehuala, Addis Ababa University, Ethiopia

Workshop: Mathematical Modeling of Infectious Diseases in Africa

June 25 - 27, 2007

Organizers:

Brenda Latka, (Program Chair), DIMACS
 Wayne Getz, UC Berkeley
 Abba Gumel, University of Manitoba
 Fritz Hahne, AIMS
 John Hargrove, SACEMA
 Simon Levin, Princeton University
 Edward Lungu, University of Botswana
 Fred Roberts, DIMACS
 Alex Welte, Wits University

US Participants:

Shweta Bansal, University of Texas, Austin
 Steven Bellan, Berkeley
 Carlos Castillo-Chavez, Arizona State
 Mingziang Chen, NC A&T State University
 Dominic Clemence, NC A&T State University
 Ashley Crump, Howard University
 Lily Davidoff, NJIT
 Jonathan Dushoff, Princeton University
 Nina Fefferman, DIMACS
 Matt Ferrari, Penn State University
 Dylan George, Colorado State University
 Wayne Getz, University of California, Berkeley
 John Glasser, CDC Atlanta
 Moses Haimbodi, Lincoln University
 Chris Langhammer, Rutgers University
 Brenda Latka, DIMACS
 Ramanan Laximinarayan, Resources for the Future
 Suzanne Lenhart, University of Tennessee
 Simon Levin, Princeton University
 James Lloyd-Smith, Penn State University
 Devroy McFarlane, Howard University
 Martin Meltzer, CDC Atlanta
 Akongnwi Mformbele, Lehigh University
 Sean Moore, Oregon State University
 Asamoah Nkwanta, Morgan State University
 Anthony Ogbuka, Morgan State University
 Anike Oliver, Howard University
 Camisha Parker, Virginia State
 Alex Perkins, University of California, Davis
 Sarah Radke, University of North Carolina
 Danielle Robbins, Arizona State University
 Helen Roberts, Montclair State University
 Fred S. Roberts, DIMACS
 Sourya Shrestha, University of Michigan
 Althea Smith, North Carolina State
 Evelyn Thomas, Howard University
 Alicia Urdapilleta, Arizona State University
 Holly Vuong, Rutgers University
 Nakeya Williams, Morgan State University
 Abdul-Aziz Yakabu, Howard University

South African Participants:

Folashade Agosto, Federal University of Technology Akure, Nigeria
 Thembile Mzolo, University of KwaZulu Natal
 Ibrahim Elmojtaba, University of Khartoum, Sudan
 Azamed Gezahagne, Addis Ababa University, Ethiopia
 Abba Gumel, University of Manitoba
 Fritz Hahne, AIMS
 John Hargrove, SACEMA
 Moathodi Kgosimore, Botswana College of Agriculture
 Tomlinson Kyle, University of KwaZulu Natal

Edward Lungu, University of Botswana
 Matadi Maba, University of Kwa-Zulu Natal, South Africa
 Zindoga Mukandavire, National University of Science and Technology, Zimbabwe
 Gesham Magomedze, National University of Science and Technology, Zimbabwe
 Gilbert Makanda, University of Zimbabwe
 Theresia Marijani, University of Stellenbosch
 Tom McWalter, University of Witwatersrand
 Senelani Dorothy Musekwa, National University of Science and Technology, Zimbabwe
 Faria Nyabadza, University of Botswana
 Wandera Ogana, University of Nairobi
 Daniel Okuonghae, University of Benin, Nigeria
 Tinevimbo Shiri, University of Witwatersrand
 Alex Welte, University of Witwatersrand
 Selamawit Woldesenbet, University of Western Cape

Other Collaborators

The project involved scientists from numerous institutions in numerous countries. The resulting collaborations also involved individuals from many institutions in many countries.

Partner Organizations

African Institute for Mathematical Sciences (AIMS) : Collaborative Research
 Individuals from the organization participated in the program planning.

South African Centre for Epidemiological Modelling and Analysis (SACEMA): Collaborative Research
 Individuals from the organization participated in the program planning.

Telcordia Technologies: Collaborative Research
 Partner organization of DIMACS. Individuals from the organization participated in the program planning.

AT&T Labs - Research: Collaborative Research
 Partner organization of DIMACS. Individuals from the organization participated in the program planning.

NEC Laboratories America: Collaborative Research
 Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Alcatel – Lucent Bell Labs: Collaborative Research
 Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Princeton University: Collaborative Research
 Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Avaya Labs: Collaborative Research
 Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Georgia Institute of Technology: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

HP Labs: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

IBM Research: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Microsoft Research: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Rensselaer Polytechnic Institute: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Stevens Institute of Technology: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Activities

US-Africa Advanced Study Institute on Mathematical Modeling of Infectious Diseases in Africa

Dates: June 11 - 22, 2007

Location: AIMS, Muizenberg, South Africa

Organizers: Brenda Latka, (Program Chair), DIMACS; Wayne Getz, UC Berkeley; Abba Gumel, University of Manitoba; Fritz Hahne, AIMS; John Hargrove, SACEMA; Simon Levin, Princeton University; Edward Lungu, University of Botswana; Fred Roberts, DIMACS; Alex Welte, Wits University

Attendance: 46

Mathematical modeling of the spread of infectious disease has a long history going back to Bernoulli's modeling of smallpox in 1760. In recent years, models have been vitally important in the development of approaches to such critical diseases as HIV/AIDS, which is of such importance to Africa. Modelers in collaboration with public health officials also played an important role during the 2003 SARS outbreaks and are already working to determine ways to contain the spread of a pending influenza pandemic.

The Center for Discrete Mathematics and Theoretical Computer Science (DIMACS), in collaboration with the South African Department of Science and Technology/National Research Foundation Centre of Excellence in Epidemiological Modeling and Analysis (SACEMA) and the African Institute for Mathematical Sciences (AIMS), held a two week Advanced Study Institute on mathematical modeling and infectious diseases in Africa, culminating in a 3-day capstone workshop.

The DIMACS/SACEMA/AIMS Advanced Study Institute provided a select group of graduate students the opportunity for exposure to a field where there is a critical shortage of people with the necessary high-level skills and which has many exciting opportunities for research and practical application. The institute trained United States and African graduate students in mathematical epidemiology and the control of emerging and re-emerging diseases. The capstone workshop enabled Institute students to interact and establish collaborations with United States and African researchers who are currently actively involved in the modeling of diseases in Africa.

The students were selected by a highly competitive process. Each student submitted an application describing their background and interests, a letter of recommendation, and a letter of commitment from a

mentor to support the continuation of the research project begun during the Institute or a new project begun afterward. Twenty-two of the students selected for the Institute were from the United States and twenty-four from Africa, creating an opportunity for establishing early collaborations between these junior researchers.

The Institute consisted of a series of lectures and tutorials on the design and analysis of models for the spread of emerging and re-emerging diseases. The first week provided a basic introduction to mathematical modeling in epidemiology at a fast pace. This introductory week was designed to allow students who have never taken an epidemiological modeling course to acquire the necessary preparatory background they needed for the second week. The second week covered more advanced material. Various modeling paradigms were discussed, as well as introductory lectures on related topics. There were a number of hands-on and computer exercises together with group projects to reinforce and extend the various concepts covered. Participants submitted proposals for research projects they would complete after the Institute, under the supervision of a mentor.

The institute was held at the African Institute for Mathematical Sciences (AIMS), located in Muizenberg, a small seaside suburb of Cape Town and an area of outstanding natural beauty. Lecturers and students all lived and dined at AIMS, allowing for maximal contact time in an informal and collegiate setting.

The main instructors were as follows. All are experts in mathematical modeling of infectious disease.

- Jonathan Dushoff (Princeton University)
- Wayne Getz (University of California Berkeley)
- Abba Gumel (University of Manitoba)
- Suzanne Lenhart (University of Tennessee)
- James Lloyd-Smith (Penn State University)
- Edward Lungu (University of Botswana)

Special Lecturers:

- Martin Meltzer, CDC
- Fred Roberts, DIMACS

The results of the exit questionnaire show that the Institute was very well received by the students. Asked how their level of knowledge of mathematical modeling changed because of attending this Institute, the average reply was 3.6 where 4 represents a great deal and 1 represents none. Using the same scale for the question of how their level of knowledge of epidemiology changed the average reply was 3.5.

We designed the Institute to encourage collaboration among the students and between the students and the lecturers. Feedback indicates we met this goal. The average rating of the value of the scientific interactions with other participants was 4.6 and with lecturers was 4.7, where 5 represents very valuable and 2 represents no value. We used 1 for no interactions and no one gave that rating.

Workshop: Mathematical Modeling of Infectious Diseases in Africa

Dates: June 25 - 27, 2007

Location: Stellenbosch, South Africa

Organizers: Brenda Latka, (Program Chair), DIMACS; Wayne Getz, UC Berkeley; Abba Gumel, University of Manitoba; Fritz Hahne, AIMS; John Hargrove, SACEMA; Simon Levin, Princeton University; Edward Lungu, University of Botswana; Fred Roberts, DIMACS; Alex Welte, Wits University

Attendance: 74

DIMACS, SACEMA, and AIMS held a 3-day workshop on mathematical modeling and infectious diseases in Africa. The workshop brought together scientists and students from the US and Africa. The aims of the workshop were to further research on the modeling of diseases in Africa and identify future research challenges.

Mathematical modeling has provided new insights on important issues such as drug-resistance, rate of spread of infection, epidemic trends, and effects of treatment and vaccination. Yet, for many infectious diseases, and in particular many diseases affecting Africa, we are far from understanding the mechanisms of disease dynamics. The modeling process can lend insight and clarification to data and theories. To get the maximum benefit out of mathematical models, however, one needs to specialize them, test assumptions in specific contexts and populations, gather local data to help define key parameters, etc. This workshop developed collaborations and communications among US and African senior and junior researchers on these issues, to benefit both sides in their research and the important public health applications of that research.

This workshop served as a capstone to an Advanced Study Institute, held at AIMS in Muizenberg, South Africa, on June 11-22, 2007, to train graduate students and postdoctoral fellows from the US and Africa in mathematical epidemiology and the control of emerging and re-emerging diseases. The students who participated in the Advanced Study Institute were prepared by the Institute to participate fully in the workshop.

The results of the exit questionnaire were very positive. The average rating of the overall satisfaction/value of the workshop was 4.4 where 1 represented low and 5 represented excellent. The average rating of the how well the workshop achieved the goal of including highest quality research and stimulating research in emerging topics was 4.3. The average rating of how well the workshop achieved the goal of bringing together people/questions/ideas from various areas of epidemiology, mathematics and/or other fields was 4.3. The table below shows the percentage of the 30 questionnaire respondents who made the type of new contacts indicated.

67%	Faculty-student	50%	Student-student	30%	Faculty-faculty
40%	Researcher-faculty	5%	Postdoc-faculty	37%	Math-epi
17%	Industry-academia	80%	African-nonAfrican	7%	Other

Twenty-seven of the respondents said that they are anticipating following up with contacts they made at this workshop on papers or research.

Workshop Themes

Evaluating the Potential Consequences of Emerging and Re-emerging Diseases

Presentations and discussions explored models that allow the determination of cost-effective strategies to combat the spread of deadly diseases using the limited resources available. Simon Levin, Princeton, began the session with a review of some classical and more recent results, with emphasis on influenza, and newly emergent problems connected with the rise of antibiotic resistance. John Hargrove, SACEMA, Abba Gumel, University of Manitoba, and James Lloyd-Smith, Penn State, each gave talks about various aspects of HIV/AIDS.

The Design and Evaluation of Cost-effective and Sustainable Strategies for Combating Disease Spread in Africa

Modelers shared ideas on the design of affordable strategies that can lead to effective control of the key diseases in Africa such as HIV/AIDS and malaria. Various modeling paradigms were discussed, with discussions aimed at determining cost-effective approaches. Talks addressed the epidemiology, immunology and evolutionary aspects of the endemic African diseases considered. A major theme was the specific challenges and opportunities arising from the increasing availability of data from African studies. Edward Lungu, University of Botswana presented a model for HIV treatment in the presence of multiple HIV-strains. Dominic P. Clemence, North Carolina A&T University, discussed the intervention impacts of concurrent HIV and TB epidemics. John Glasser, CDC/CCID/NCIRD, gave an evaluation of targeted influenza vaccination strategies via population modeling.

Economic Aspects of Disease Epidemiology

Additional pertinent issues such as health economics and the economic aspects of disease burden and the potential of interventions were also featured prominently in this workshop. Martin I. Meltzer, CDC, created a lot of discussion with his talk on making models useful for policy makers. Ramanan Laxminarayan, Resources for the Future, discussed the economic aspects of disease epidemiology. Senelani Hove-Musekwa, National University of Science & Technology gave a presentation on modeling the epidemiological and economic impact of HIV/AIDS with special reference to Zimbabwe.

Panel on Next Steps

The workshop concluded with a panel discussion on next steps. John Hargrove, SACEMA, said that SACEMA's goal is to increase the enrollment of female and minority students. At present, there are not enough available candidates.

Fritz Hahne, AIMS, said that disease modeling for Africa needs to reflect the causative factors of these diseases, the economic and social problems including lack of infrastructure. AIMS is also starting training programs in institutions around Africa. Whatever is being done should focus on problems of Africa. The partnership with DIMACS is a welcome and productive idea.

Simon Levin, Princeton University, spoke about partnerships, international collaborations and research. There are great opportunities for research and for strengthening partnerships with other institutions that focus on relevant issues. He recommended letting African students visit institutions in the US.

Carlos Castillo-Chavez, Arizona State University, said there is a need for role models, who may not necessarily come from South Africa, to inspire South Africans to earn advanced degrees. There is value in continuing to work with African students, who will invariably get involved with the real African communities. The bottom line remains to use education in addressing some of the pressing issues and problems of the continent.

Edward Lungu, University of Botswana, said there is a shortage of manpower and funding for educational training in most universities in Africa but remarked on the determination on the part of aspiring students and staff who are making great strides despite the great odds that are facing them.

Fred Roberts, DIMACS, commented on the need to connect with African students and scientists who know more of the problems of the African continent. He made mention of some organizations such as PCMI at Princeton, Park City in Utah, Math/Bio Institute at Ohio State University etc. that could potentially be helpful. In addition, he pointed out the need to introduce the next generation of researchers to the global network of science research.

Dr. Roberts also talked about inviting some African undergraduates and researchers to participate in US institutions. This and other initiatives are part of the five-year plan being developed at DIMACS. There is also the need to get more public health professionals involved in this kind of training and workshops. He talked about mid-career training for the application of mathematics, making mention of DIMACS program, RECONNECT, for college faculty. He regretted the absence of women on the convening panel.

Finally, he pointed out the need for current Advanced Study Institute participants to keep the panel informed with their ongoing projects since there might be the opportunity to have them present their project later.

Ashley Crump, one of the ASI students responding to the panels' request for comments, spoke of the things she had learned while at the Institute. She said we need to get other students, math and non-math majors alike, to learn more about the uses of mathematics in addressing some real life problems.

Findings

As the Advance Study Institute and capstone workshop were held in June of this year, it is too early to expect research findings. However, the student participants in the Advanced Study Institute are currently working on projects developed at the Institute. Below is a description of each of these projects.

Optimal strategy for breastfeeding to prevent postnatal HIV transmission in South Africa

Selamawit Woldesenbet, University of Western Cape
Zelalem Nigussa, University of Stellenbosch

Mentor: Suzanne Lenhart, University of Tennessee

Mother to child transmission of HIV is the first cause of death in children less than 14 years of age in sub-Saharan countries. After the development of potent and simple antiretroviral (ARV) drugs to prevent transmission during pregnancy and delivery, postnatal transmission has become a major challenge in mother to child transmission. Breastfeeding is the major route of postnatal HIV transmission. Avoiding breastfeeding can eliminate 100% the transmission after delivery. However, for most developing countries, breastfeeding has nutritional, immunological and cultural advantages. WHO recommends the decision to be made by mothers to either avoid all breastfeeding, if replacement feeding affordable, feasible, accessible, sustainable and safe, or practice exclusive breastfeeding (EBF) followed by early and rapid cessation. Policy guidance is needed on feeding strategies that could lower the risk of postnatal transmission while also minimizing non-HIV related risks.

The argument is made in recent studies that EBF has no greater risk of HIV/ mortality than formula feeding, if given for a short period (no more than 3 months) of time followed by rapid weaning. This project seeks to find the optimal strategy for EBF to increase the survival of children at risk of HIV transmission. Time series data collected from selected sites in South Africa will be used to estimate the parameters in a model using discrete ordinary differential equations.

Intervention strategies in malaria using optimal control

Gilbert Makanda, University of Zimbabwe
Theresia Marijani, University of Stellenbosch
Victoria Nwosu, AIMS
Ndubuisi Omaghali, AIMS

Mentor: Suzanne Lenhart, University of Tennessee

Malaria is responsible for the death of about 200 to 500 million people in Africa and most of them are children under the age of five. It is a disease caused by a protozoan parasite that comes in four serotypes; *Plasmodium falciparum*, *Plasmodium vivax*, *Plasmodium malarie*, and *Plasmodium ovale*. This disease is transmitted by a female anopheles mosquito. We introduce a simple deterministic model of malaria with two populations, human and vector, interacting with each other. This model introduces two intervention strategies (controls) to reduce the prevalence of the disease. These include treatment of infected humans and eradication of the susceptible mosquito population. We show that the two controls quickly reduce the incidence of malaria in humans. Interventions without vector control are likely to be ineffective. We determine the optimal control analytically and then do numerical simulations of different intervention strategies.

Optimal control measures to prevent the incidence of TB in an HIV population

Folashade Augusto, Federal University of Technology Akure, Nigeria
Margaret Modupe Kajotoni, AIMS

Gesham Magombedze, National University of Science and Technology, Zimbabwe
Anthony Ogbuka, Morgan State University
Daniel Okuonghae, University of Benin, Nigeria
Alicia Urdapilleta, Arizona State University
Nakeya Williams, Morgan State University

Mentors: Suzanne Lenhart, University of Tennessee, and Edward Lungu, University of Botswana

We are investigating whether pre-treatment of tuberculosis in HIV positive individuals as well as post-treatment of TB in individuals who are HIV positive and have TB, reduces the frequency of tuberculosis within the HIV positive population and overall mortality.

A model of transovarial transmission and maintenance of seasonally epidemic Chikungunya

Steven Bellan, UC Berkeley
Althea Smith, North Carolina State University
Thibaut Zafack Takadong, University of the Witwatersrand

Mentor: Martin I. Meltzer, CDC

Chikungunya fever is an emerging vector-borne disease. In humans, the clinical manifestations of the disease are similar to Dengue fever: fever and skin rash. Mortality is extremely infrequent. Chikungunya may usually be distinguished from Dengue by the additional characteristic symptom of arthralgia (extreme joint pain). Chikungunya's epidemiology also mirrors that of Dengue. The two diseases occur in the tropics, are transmitted by *Aedes* mosquitoes, exhibit seasonal peaks in transmission corresponding to peak vector density, and appear to cause epidemics in human populations without requiring non-human host reservoirs. Due to these similarities, Chikungunya and Dengue cases have often been confused clinically. Misidentification and rarity has led to poor documentation of Chikungunya. Yet recent epidemics across the western and northern Indian Ocean have brought the disease to international attention and highlight the importance of understanding its epidemiology.

Chikungunya virus was first characterized in 1952 in Tanzania. The virus persists endemically at low prevalence in rural western Africa. In this region, Chikungunya virus is characterized by numerous vector

and host species. Transmission is intense and human populations exhibit high levels of immunity. In contrast, south-east Asia reported numerous Chikungunya epidemics throughout the second half of the 20th century. These epidemics appeared to be sustained solely by human-vector transmission (i.e. independently of any reservoir host), with *Ae. aegypti* or *Ae. albopictus* as vectors. While these epidemics occurred infrequently, they swept through largely non-immune populations with high attack rates (usually greater than 30%). The magnitudes of the recent epidemics in La Reunion, an island east of Madagascar, and India are particularly troubling. Since March of 2005 over a third of the 750,000 people living on La Reunion have reported symptoms of Chikungunya fever. Due to under-reporting, the number of cases in India remains unknown, but estimates range from 1 to 6.5 million. There have been many explanations for the occurrence of large-scale Chikungunya epidemics. New strains of virus and/or vectors have been implicated in the increased vector competence of *Aedes* mosquitoes. Vector competence, however, is influenced by a variety of factors. These include vector lifespan, preference for biting human vs. non-human hosts, susceptibility to infection, infectiousness when infected, population density, and transovarial transmission (transmission of the virus between adult mosquitoes and their offspring, hereafter TOT). While all these factors warrant attention, we choose to focus on the potential effects of TOT on Chikungunya epidemiology in La Reunion where *Ae. albopictus* serves as vector. An important question for both public health officials and mathematical epidemiologists is "How many susceptible hosts are required for an epidemic disease to persist?" For seasonal diseases a corollary to this question is "How many susceptible hosts are required for an epidemic disease to persist inter-seasonally?" This question is of primary importance to the La Reunion outbreak. In the summer of 2005, La Reunion experienced a relatively small initial outbreak with an incidence rate peaking above 400 cases per week. During the subsequent winter Chikungunya incidence fell to 100 cases per week, misleading epidemiologists into thinking the worst was over. However, the summer of 2006 saw a peak incidence rate of over 40,000 cases per week. Now that more than a third of the island's population is immune to the virus, will the disease be able to cause another epidemic in the coming summer? If so, what will the scale of the epidemic be? The answers to these questions depend on the winter dynamics of Chikungunya. During the winter when vector populations are small and human infection is rare, TOT may allow the virus to persist at higher prevalence in vectors. While some laboratory studies failed to find TOT of Chikungunya in *Ae. albopictus*, Zytoon et al. demonstrated TOT in *Ae. albopictus* coinfecting with heartworm (*Dirofilaria immitis*). Thus, the presence of TOT of Chikungunya in nature remains disputed. This project aims to clarify the extent to which TOT could affect Chikungunya dynamics using a mathematical model. We will fit models with different TOT rates to the La Reunion data. With numerous stochastic simulations for each model, we will calculate the probability that Chikungunya will persist during the upcoming winter as well as the magnitude of the next summer's epidemic under each TOT rate.

Economic impact of HIV in South Africa

Danille Robbins
Arizona State University

Mentor: Martin I. Meltzer, CDC

South Africa has the best economy in the entire continent of Africa; it provides 40% of the industrial output and 45% of the mineral production in Africa while supplying 50% of the entire continent's electricity. Although South Africa has established significant economic success, it is also threatened by the largest HIV-infected community in the world. Based on multiple macro-economic models, if the current infection rate of HIV is not lowered in South Africa, the Gross Domestic Product will begin to decrease significantly. The lower GDP will result from the reduced labor productivity because HIV causes more sick and personal (funeral) days. South Africa needs its economy to continually grow to reach its goal of cutting the unemployment level in half by 2010. HIV may impede these efforts. By

modeling the burden that each HIV infected age group (1-5,6-14,15-29, 30-45, 45 & older) has on the current economy, we can implement strategies that will maintain GDP growth in South Africa.

Cassava Mosaic Disease

Lily Davidoff, NJIT

Mentor: Wayne Getz, UC Berkeley

Cassava Mosaic Disease (CMD) has been present in East Africa for over a century. It is only over the past few decades that the spread has become extensive, reappearing first in north-central Uganda in the late 1980's. Today it covers much of East and Central Africa, and all of Uganda, western Kenya, Southern Sudan, eastern Democratic Republic of Congo (DRC), north-western Tanzania, and all of Burundi and Rwanda. The spreading of CMD has had an enormous impact on the production of cassava, a major food staple in the sub-region. Because cassava is easy to cultivate and can be used in a variety of ways, it is believed that it could be used to improve hunger issues in many of the countries within Africa. Because of the impact that CMD has had on the food security of many African households, both economically as harvested produce to sell and personally as an important food source, we see the urgency in determining how to best curb the spread of CMD. In rural areas, agriculture tends to be the primary economic activity. Thus, if we can control the rate at which CMD spreads, increasing the production of healthy cassava, we could potentially create more jobs for individuals. By doing so we could improve agricultural production which may reduce food insecurity and poverty in Africa. Hence, I would like to further investigate the pattern in which CMD is spreading, and see what control methods would be most effective. Once I have developed a model of the spreading pattern using graph or network theory, I will look more closely at the effects of phytosanitation and roguing on the spread of CMD. The model could take into account various factors, including minimizing the monetary cost of spread control. I would also examine the effects of civil and or political unrest on the spreading of CMD. I would also take into account the socioeconomic and demographic factors resulting in the failure of individual farmers to comply with particular strategies for controlling the disease.

Analyzing the impact of low and high risk behaviors in HIV+/AIDS infectives on antiretroviral (ARV) drug resistance

Devroy McFarlane, Howard University

Azamed Gezahagne, Addis Ababa University, Ethiopia

Ibrahim Elmojtaba, University of Khartoum, Sudan

Joy Okonkwo, AIMS

Lois Olatayo, AIMS

Folashade Agosto, Federal University of Technology Akure, Nigeria

Akongnwi (Clement) Mformbele, Lehigh University

Maba Matadi, University of Kwa-Zulu Natal, South Africa

Mentors: Abba Gumel, University of Manitoba, and Edward Lungu, University of Botswana

We will examine the behaviors of low and high risk HIV/AIDS infected groups to analyze their effect on antiretroviral drug resistance. Our ultimate goal is to address the question of whether low and/or high risk behaviors somehow influence ARV drug resistance in HIV/AIDS infectives. That is to say, do risk behaviors impact the emergence of a drug-resistant HIV/AIDS strain? If, say, the high-risk group or vice versa contribute more to the emergence and/or transmission of the ARV drug resistance strain, then we can ask another more immediate question. Should one pay more attention to the high-risk group in an attempt to reduce drug resistance (or find ways of preventing drug-resistance) in that group? For example, implementing counseling as part of the treatment process may educate and caution a high risk infective

from acquiring multiple strains and/or transmitting the HIV strain. Or should one concentrate on developing better drugs that are not resistant to the HIV/AIDS disease, in which case more attention is given to the drug-resistant group? Mathematically, this compels one to look at the role of optimal control in helping to decide on potential strategies for reducing ARV drug resistance.

HIV in bisexual populations

Evelyn Thomas, Howard University

Mentor: Abba Gumel, University of Manitoba

The “down-low” effect is a term recently coined for the practice of covert bisexuality and/or homosexuality, specifically among African American males. Due to the social stigma of identifying with homosexual or bisexual orientations, these men engage in homosexual activity secretly while maintaining a heterosexual cover. There has been much anecdotal speculation as to the linkage of the “down low” to the HIV/AIDS crisis in the Black American community, however, the “Centers for Disease Control and Prevention has never cited men on the down-low as the cause.” Research in this area is limited due to the difficulty in identifying and gathering data on this particular community. In an effort to control the spread of HIV, we will look at a co-infection model of HIV and curable sexually transmitted diseases (namely gonorrhea). We will determine the measures that need to be taken to control these other diseases, which in turn will decrease the spread of HIV in this bisexually mixing population.

Pre-infection education effect on HIV

Ashley Crump, Howard University

Anike Oliver, Howard University

Zelalem Nigussa, University of Stellenbosch

Mentors: Abba Gumel, University of Manitoba, and Edward Lungu, University of Botswana

HIV has rapidly become a pandemic, affecting people from all parts of the world. It is our belief that education may be one major factor that can control the spread of this disease. We plan to create a model that will capture the effects of pre-infection education on transmission of HIV in a population. The model will consider age structure in the susceptible class. In doing so, we hope to determine which age class in a population should be educated most in order to reduce the number of individuals with HIV in a given time period. We will use differential equations to build our deterministic model.

Genetically modified mosquitoes and malaria

Alex Perkins, University of California, Davis

Mentor: Abba Gumel, University of Manitoba

A number of challenges have plagued public health officials seeking to eliminate malaria in areas in which it is endemic. Mosquitoes quickly evolve responses to insecticides, a suitable vaccine is not yet available, and the potential of vaccines to eliminate malaria in endemic areas is questionable. Clearly, alternative interventions are needed. One such alternative exists in the form of introducing transgenic mosquitoes into natural populations. These mosquitoes, whose genomes are modified such that Plasmodium transmission is impaired, have the potential to eliminate or greatly reduce the prevalence of malaria in targeted areas. The application of this technique is not yet possible, but advances are being made and mathematical modeling can shed light on the potential of this approach.

I propose to formulate a simple malaria model with the inclusion of a transgenic mosquito class. Fundamental to the model will be the inclusion of competition between transgenic and non-transgenic mosquitoes, the parameters of which can be informed by the previous work of others that demonstrated that transgenic mosquitoes display increased fecundity and reduced mortality when feeding on hosts infected with Plasmodium. Because mortality is a major difference between these two mosquito classes, the inclusion of a latent period in the mosquito classes is essential, as mosquito demography and disease transmission operate on comparable timescales.

Once I formulate a simple yet suitable model of malaria transmission with the inclusion of a transgenic mosquito class, the first task I anticipate performing is to identify equilibria and their stability and to calculate R_0 as a function of parameters relevant to life history differences between transgenic and non-transgenic mosquitoes. The benefit of such a formulation is that it would provide a means of evaluating the potential for success upon introducing transgenic mosquitoes to a specific population for which other epidemiological parameters may be known.

Possible extensions would be to include factors known to be important to malaria dynamics (e.g., acquired immunity) and to evaluate the potential of genetic approaches for spreading the resistance allele throughout mosquito populations (i.e., meiotic drive, endosymbionts like Wolbachia, transposable elements). In particular, I am interested in developing a model that includes spread of the allele for Plasmodium resistance via attachment of such an allele to endosymbiotic Wolbachia, as the dynamics of this genetic drive mechanism are well understood in *Drosophila* and could realistically be extended to *Anopheles* or other disease vectors.

A mathematical analysis of an HIV/AIDS model with risk groups

Thembile Mzolo, University of KwaZulu Natal
Zindoga Mukandavire, National University of Science and Technology, Zimbabwe

Mentor: Jonathan Dushoff, Princeton University

The HIV/AIDS epidemic has remained one of the leading causes of death in the world and has been destructive in Africa with Sub-Saharan Africa remaining the epidemiological locus of the epidemic. The detrimental impact of the HIV/AIDS epidemic is more strongly felt in developing countries. In Sub-Saharan Africa countries, declines in national HIV prevalence associated with changes in behavior and prevention programs have been observed in two countries, Kenya and Zimbabwe. In all affected countries with either high or low HIV/AIDS prevalence, HIV/AIDS hinders development, exacting a devastating toll on individuals and families. In the hardest-hit countries, it is erasing decades of health, economic and social progress, reducing life expectancy by years, deepening poverty, and contributing to and exacerbating food shortages. This study formulates and analyses a deterministic mathematical model for HIV/AIDS transmission dynamics that classifies the population into three basic subgroups: susceptibles, infectives, and AIDS cases. The subgroups in the population are divided into two classes, consisting of individuals involved in high-risk sexual activities and individuals involved in low-risk sexual activities. HIV/AIDS models with risk groups due to sexual activities have been studied by several groups of researchers. We differ from these studies in that we present an in-depth analysis of the qualitative dynamics of HIV/AIDS and extend the model to incorporate HIV/AIDS intervention strategies. It is expected that the results will help in the design of control and intervention strategies. The project will provide a better understanding of the spread of HIV among individuals classified as high or low risk.

Trypanosomiasis

Sean Moore, Oregon State University
 Sourya Shrestha, University of Michigan
 Kyle Tomlinson, University of KwaZulu Natal
 Holly Vuong, Rutgers University

Mentors: Jonathan Dushoff, Princeton University, James Lloyd-Smith, Penn State University, John Hargrove, SACEMA

Human African Trypanosomiasis is an infectious disease caused by several subspecies of the protozoan *Trypanosoma brucei*. The parasite is obligately vectored by multiple species of tsetse flies (*Glossinia* spp.), therefore limiting the distribution of the parasite to areas where the vectors can survive and reproduce. Two primary subspecies, *T. brucei gambiense* and *T. brucei rhodesiense*, are responsible for a large proportion of human infections in sub-Saharan Africa. *T. b. gambiense* is found in western Africa and *T. b. rhodesiense* is located in eastern and southern Africa. The former subspecies causes chronic infection and circulates within the human population while the latter results in acute infections sourced from animal reservoirs. The reservoirs of *Trypanosoma* include domestic animals as well as wildlife species. We shall focus our interests on *T. b. rhodesiense*. Periodic epidemic outbreaks of *T. b. rhodesiense* in humans have been recorded in east and southern Africa for more than 100 years, and these outbreaks often occur at historical foci where the parasite appears to persist at endemic levels in the reservoir populations between outbreaks. We are interested in understanding the mechanisms that would lead to such observations. Here we outline a few of the questions and directions that we have at this initial stage of the research.

1. There is indication from some papers that tsetse have a strong preference for animals over humans. Feeding on humans is considerably more risky for the tsetse since humans are better at getting rid of the flies. How do vector-reservoir interactions and relative transmission rates influence the probability of epidemics in the human population? Could this preferential feeding pattern explain the population level disease pattern of intermittent epidemic events with long periods of few infections? And if so, what environmental factors will lead the tsetse flies to change their feeding patterns to increased human biting? We have started with a simple compartmental deterministic model that embeds the preferential feeding patterns. We will develop the model further to address these and additional questions.
2. The pattern of intermittent epidemics with long periods of low or no prevalence observed in human populations could possibly be epidemic fadeouts due to demographic stochasticity. *T. b. rhodesiense* are known to be fairly acute in their infection, and persistence of such disease faces considerable risk of fadeout at the end of an epidemic when the susceptible population depletes. Could demographic stochasticity play a substantial role in the distribution and the behavior of trypanosomiasis epidemics?
3. Tsetse flies are known to be sensitive to changes in temperature. Slight increases in the temperature may allow faster reproduction of the tsetse flies. However, large temperature increases could have negative effects on tsetse reproduction. Therefore, changes in climate could affect the future risks of trypanosomiasis epidemics as these are dependent on the distribution of tsetse flies. What is the effect of climate change on the future distribution of tsetse flies and hence, trypanosomiasis?
4. *T. b. gambiense* and *T. b. rhodesiense* have distinctly different infection patterns (the former is chronic and the latter is acute). It is apparent that the two subspecies are geographically separated, where *T. b. gambiense* is found in west and central Africa, and *T. b. rhodesiense* is found in southern and eastern Africa. It is possible that these differences in distribution and behavior are related to the historical human population distribution in these regions. Can the differences in infection characteristics and geographical distribution of *T. b. gambiense* and *T. b. rhodesiense* be explained by historical human social structure and demography?

Indirect effect of the RTS,S malaria vaccine

Illyes Boukabet, AIMS
 Sarah Radke, University of North Carolina
 Angelina Mageni Lutambi, AIMS

Mentors: Jonathan Dushoff, Princeton University, and James Lloyd-Smith, Penn State University

Several candidate malaria vaccines are currently in development. The most promising of these candidates is GlaxoSmithKline's RTS,S vaccine. In a clinical trial setting, the malaria incidence reduction attributable to the vaccine was 45%. Because RTS,S vaccine targets the pre-erythrocytic stage of *Plasmodium falciparum*, it is possible that in addition to direct protection conferred by the vaccine, indirect protection of unvaccinated individuals may also result. Maire et al. modeled the impact of introducing RTS,S vaccine into the Expanded Program on Immunization in Sub-Saharan Africa and found little, if any, transmission effect. They surmise that the main reason for this was that vaccination was limited to infants and *Plasmodium falciparum* circulates in all age groups. It is this question of the indirect effect (also commonly called transmission effect) of the RTS,S malaria vaccine that we intend to model for our project. Unlike Maire et al. however, we will model a vaccination program that includes all ages.

Effects of the healthcare system on the evolution of TB drug resistance

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 Dylan George, Colorado State University
 Christopher Langhammer, Rutgers University
 Gesham Magombedze, National University of Science and Technology, Zimbabwe
 Tinevimbo Shiri, University of Witwatersrand

Mentors: Jonathan Dushoff, Princeton University, and James Lloyd-Smith, Penn State University

The evolution of treatment resistance in a pathogen is a global health problem (e.g. HIV, TB, MRSA). One potential mechanism for the evolution of drug resistance includes differences in population pathogen dynamics due to variation in the application of healthcare in urban versus rural areas. Healthcare systems in many countries can be crudely characterized by a gradient of consistent care in urban settings to less consistent care in rural settings. Healthcare in rural areas is prone to additional problems due to poorer standards of living, lower education levels, inferior quality and density of healthcare providers, periodic and highly localized failures of DOT programs (directly observed therapy, which is the administration of every scheduled dose of a treatment drug by a health care worker), and periodic lapses in drug availability. These conditions encourage incomplete treatment regimens and create selective pressures on the pathogen that favor drug resistant strains. Inconsistency of rural healthcare systems can also create discontinuities in the overall coverage of healthcare for an entire population (rural and urban). These discontinuities could facilitate different selective topographies allowing the evolution of resistance.

Heterogeneities across population structure are important drivers of the ecology and evolution of infectious disease, and incorporating them into a model structure may allow us to study previously poorly understood dynamic behaviors. While pathogen evolution arising from some heterogeneities within a population are well studied, the effects of heterogeneities associated with an intervention strategy on the evolution of a pathogen are frequently disregarded.

The specific goals for this study are:

- Quantitatively characterize the urban-rural gradient of healthcare application.

- Consider how the mechanisms that drive pathogen evolution of drug resistance may differ from pathogen evolution of virulence.
- Consider how discrete failures of the rural healthcare system affect pathogen evolution on a local and regional level.
- Consider if the modular structure of an urban-rural healthcare system could impact evolution of virulence and epidemiological dynamics.
- Explore other heterogeneities (variation in contact structure, differences in population densities, etc.) that may exist along the urban-rural gradient as well.

We make the following hypotheses:

- Different selective pressures created by heterogeneous application of healthcare across urban and rural settings facilitate the repeated appearance of drug-resistant strains of pathogens.
- Under the correct conditions a treatment-resistant pathogen will be able to migrate from the rural centers where it originated toward the urban population centers, exhibiting the inverse of typical pathogen-population spatial dynamics (e.g., pre-vaccination measles in the UK).

Our model has a modular structure, which allows us to build upon each existing piece of the model. In order to characterize the gradient of healthcare, we first design a measure of healthcare success that takes into account various factors including drug availability, drug delivery, and treatment compliance. In the first step we design a population-level (between-host) model for the spread of TB that incorporates transmission as a function of treatment. We study the sensitivity of the healthcare parameter on the success of the resistant strains. In the second step, we add a within-host component to the between-host model that explicitly models the evolutionary dynamics of the pathogen within the host. Finally, we extend the between-host model to incorporate meta-population structure representing an urban area and the rural areas surrounding it.

Training and Development

The primary objective of the Advanced Study Institute is training and development. Below are comments from the students on the success of the Institute and the capstone workshop.

Comments from African Students

“It was really a privilege for me to be part of both programs on the use of mathematical models for understanding the spread of infectious diseases as well as propose control strategies for containing these diseases. The ASI has greatly increased my knowledge of dynamical tools for analysing the models as well as provided new ways for developing mathematical models, especially stochastic models, discrete and network models which I have never used in any of my previous models.

In respect of the continuous models, it’s amazing to state that I was able to carry out a seemingly complex analysis that has eluded me for the past six months in just one hour! Many thanks to the brilliant lecturers that took part in the ASI. For the first time I was able to implement an optimal control model within the two days in was taught!

The collaboration between I and some of the participants has already yielded fruits. Why, I have already established some contacts with the American students as well as the African students that we are about coming up with a paper for a model we are working on! Moreover the enthusiasm of the participants is highly ‘contagious’. We are very eager to work with each other, an experience I was not able to establish even when I was at Oxford University for my Masters Degree.

I am using this opportunity to thank sincerely all the members of the organising team for a wonderful idea well executed. I pray that this does not stop here. I will suggest that the 40 participants should be kept together as much as possible to really establish a very strong bond between us and keep the academic 'fire' burning. I believe that the idea of raising younger generations of mathematical epidemiologist from both continents will go a long way in establishing firmly this fledging field of human endeavour. The organisers should make provisions to bring us back together say in six months time for more interactions and providing solutions to more complex problems.

I thank you for giving me the opportunity to move out of the academic 'island' I had been in for a long time, into the 'mainland' of academic interaction and a 'world' of knowledge." Daniel Okuonghae, University of Benin, Nigeria

"I'm a Sudanese student; actually I finished my Master's two years ago and I didn't start my PhD yet because I hadn't have an advisor to guide me and tell me what to do, but fortunately I heard about the ASI from AIMS website and then I applied and I have been selected to attend it and that was the most good thing that happen to me ever. And now when the ASI finished I got a lot of benefits, I don't have an advisor but I have more than one. I have Lungu, Gumel, Jamie, Susan, Martin and Azziz, and even great names like Carlos, and also I have a good plan for my future because I discovered not just new areas of research, but I learned how to create my research area, and I have a project to work with this year, and I hope to be my first published paper, and also I got a supervisor for my PhD, yes prof. Lungu accept to be my supervisor and I will start my PhD with him at SACEMA. In my career I got a lot because here in Sudan there is no one in the field of Bio-Mathematics, so I guess I will be the first one and I'm planning to start a research group in the Faculty of Mathematical Sciences – University of Khartoum with the Institute of Endemic Disease – Faculty of Medicine – University of Khartoum as a collaborators, and I start that by giving a presentation with the name (An Introduction to Bio-Mathematics) in my faculty to the graduate students and hopefully I will find some of them interesting in this field so that we can start together, and soon you will hear about our work here in Sudan. At last I want to thank you very much and to thank DIMACS, SACEMA and AIMS because this ASI changes my life totally." Ibrahim M. ELMojtaba, University of Khartoum, Sudan

"Firstly, I would like to thank DIMACS for organizing this institute. This was a life time opportunity that does not comes across anytime. We do not have these kinds of institutes here in South Africa. I learnt a lot of things that will help me in shaping my career since I am interested in modelling infectious diseases that are affecting sub-Saharan countries, especially sexually transmitted infections. The information we gathered during the course of the institute is very vital in a way that it will contribute a lot in my work and future research. Having students from Africa and United States helped us as students to get to know more about each other since we were all from different environments. This resulted in much collaboration that can results in a variety of publications. What I can say is, now I can do a mathematical modelling and do analysis which I was not able to do before since I am coming from a statistical background where we only interested in statistical modelling and analysis. The lecturers at the institute were very good and always willing to help us when we need them most, they were very approachable. At the moment I am working on a research paper for risk groups of HIV which was started during the institute. In this paper I am working with Zindoga Mukandavire (from Zimbabwe) whom I am collaborating with." Thembile Mzolo, University of KwaZulu Natal

"The course I have learned from AIMS and three days workshop stellenbosch, means alot to me, I have learned how can I use my mathematics to solve the problem of diseases,and I learned that important things is we need to work together biologist, mathematicians, statisticians and doctors. This help us mathematician like me in modelling different infectious diseases. Because before that I had a lot of questions about malaria in my head that needed to answer but that workshop help me to get answers and it change me to be researcher so that we can join together and solve the problem of diseases in the world.

The meeting of different people with different ideas it helped me to know many things, because I did not even know other types of diseases that are still a problem in this world, it helped me to know that there are diseases that have been forgotten that are still a problem in the life of people. It helped me to know different methods to solve these infectious diseases in mathematics. Real I have started to spread the news in my country to my friends that we can use mathematics to solve the problems of diseases.” Theresia Marijani, University of Stellenbosch

“I would like to first express my profound appreciation to the organizers for the invitation given me to attend the Advanced Study Institute and the Workshop: Mathematical Modeling of Infectious Diseases in Africa. The institute/workshop has been of great impact to me. It has greatly improved my understanding and interest in the subject. It provided me the opportunity of meeting with Prof. S. Lenhart, someone who before now has inspired my interest in the application of optimal control to disease control. And meeting with her has given me the opportunity to have her as a mentor.” Folashade Augusto, Federal University of Technology Akure, Nigeria

“Attending the Study Institute and Workshop on Infectious Disease Modelling has been a very worthwhile experience for me, and will provide a lasting benefit to the research that I do in future. My own background is in using modeling for terrestrial ecology, but I hope to expand some of my research interest into disease modeling.

Material: The design of the course (institute first, then workshop) was useful in setting the context of the research and the state of the knowledge. The Institute gave us the basic ideas, allowing us to evaluate current research as presented at the Workshop.

Methods: The course introduced me to a number of modeling concepts and modeling approaches (and importantly, when to use them) with which I was unfamiliar. Some of the methods I have learnt at the institute will be useful to terrestrial ecology as much as to epidemiological problems. I will of course introduce some of these methods into modeling courses that I will teach in the future.

Groupwork and Research: The disease modeling groupwork component of the Institute with which we are still presently involved has also been a worthwhile experience. Hopefully it will lead to concrete research outputs, but in addition the collaboration is also most helpful to someone like myself who has no background in epidemiology modelling, as it allows time to develop depth in the methods. Our group is examining the epidemiology of the fascinating zoonoses protist *Trypanosomiasis brucei* and its subspecies. We have identified a number of very interesting questions and hope to produce quality research, but of course there is still much literature to be read to assess what has been done and what is necessary (always the problem when launching into a new research field).

Collaboration: the institute was successful in instituting collaborations between African and American students and in fostering understanding as to the different approaches being employed. Project groups were also formed cross-continently. Interestingly it is my perception that generally the groups were formed based on education background and employing familiar methods i.e. heavy mathematical approaches united maths background students and simpler mathematical approaches united ecology background students.

To end, I would like to thank DIMACS, AIMS and SACEMA for selecting me to attend the Institute and Workshop, and the US National Science Foundation for sponsoring the Institute and Workshop. It was an enriching experience and one that should lead to sustained collaboration and research activity for myself and for others.” Kyle Tomlinson, University of KwaZulu Natal

Comments from US students

“The ASI workshop was an excellent experience that definitely exceeded my expectations. By far the most valuable part of it was getting to know and becoming friends with students and lecturers from all over Africa. It is rare to spend so much time with people from this many different countries and it is

amazing how much I learned from doing so. Through living, eating, and spending free time with students and lecturers I made friendships and found collaborators for potential future projects. I also learned much about a diversity of African cultures and feel like I have a better understanding of the continent. While having students from many different academic backgrounds (pure math, physics, ecology, public health) created obvious obstacles for lecturers, this diversity also helped me understand mathematical epidemiology from new perspectives. I find it often helps me develop a more intuitive understanding of concepts when I am with many people who are learning it from different perspectives. I enjoyed learning from other students who had more experience in certain topics as well as helping students who were less familiar with mathematical epidemiology. While I was familiar with most of the information in the first week of lecture, I have never had it taught in this way before. Modeling techniques and complexities were always presented within the grander context of their mathematical and epidemiologic justifications. I am now much better at comparing different techniques and knowing when certain ones are more appropriate. During the second week the advanced topics were taught at an extremely fast pace. This was difficult to follow at times, but necessary in order to cover the range of subjects presented. Still, I found it very useful to see things like optimal control, stochastic branching processes, and Lyapunov functions presented. Now I know why they are used and can critically examine their usage. I am quite enthusiastic about the project that my group is pursuing (assessing how vertical transmission in vectors affects the maintenance of seasonal Chikungunya epidemics). Our project has moved along surprisingly quickly. We complement each other quite well too. I have experience in disease ecology and mathematical epidemiology, Tihbaut's field is pure math, and Althea's is mathematical biology. I think with these skills I am optimistic that we will be able to create an appropriate model and use both analytical and computational tools to provide insight for public health policy makers to make decisions and for field scientists to gather appropriate data. Finally, Muizenberg was a good location to have the workshop. Although the suburb is surprisingly quiet, the thirty second walk to the beach and proximity to Cape Point attractions and Cape Town was quite convenient." Steven Bellan, UC Berkeley

"The workshops in South Africa, if summed up in one sentence, suffices as being highly enriching and rewarding in terms of gaining valuable insight into novel research ideas and establishing new international collaborations. Indeed, the workshops at AIMS as well as in Stellenbosch explored some original ideas that are helping to reduce infectious disease incidence in Africa. A case in point is the idea that male circumcision might reduce transmission of HIV/AIDS from woman to man, which in fact turned out to be a profoundly astonishing fact. It is this kind of exciting work that has commanded my interest in thinking of new research ideas for tackling infectious disease related problems.

"In fact, when I learned that we would be working in a group I was elated because I had ideas to share about a certain infectious disease, HIV/AIDS. To top things off, the group itself was exciting with diverse group of students from Ethiopia, Sudan, Congo, Nigeria, the U.S., and South Africa. Further, some of the students had a good background in mathematics, others in computer science, and others in biology.

"The first time we met in groups we immediately enjoyed working together. This was such the case that for the entire second week we worked together on our project until 2-3 AM in the morning and with smiles on our faces. We also ate together and hung out during our spare time. We still communicate almost daily via e-mail to inform each other of our progress on the research project. We divided the work so each person could contribute based on his or her expertise.

"Thank you NSF and DIMACS, because of your support my participation has lead to new collaborations as well as new research ideas. Needless to say, I have decided to work on a similar problem for my Ph.D. thesis." Devroy McFarlane, Howard University

"I felt that the two week workshop was a very worthwhile and great learning experience. As a second year graduate student in Ecology and Evolution, I truly learned a lot because many of the underlying math

concepts were new to me. My undergraduate biology major only required one quarter of calculus, therefore, I really appreciated the review session during the first week. Drs. Edward Lungu and Jamie Lloyd-Smith were great at providing lectures that were understandable for a concept that was slightly out of my reach at the start of this workshop. Prior to the workshop, I had an understanding of the biology of how a disease can be maintained and spread. With the workshop, I can see how the math models are constructed to show how pathogens are spread and maintained.

“I also enjoyed the second week of the workshop because we had lectures that touched upon other concepts of disease modeling. However, there were many different styles of teaching in a short time period that it made learning a bit more difficult. It might have been better to have fewer lecturers, but more lectures from each person. This is a difficult balance because it was great to have these highly qualified individuals come and lecture, but their lectures were a bit too fast and only provided an overview of these concepts.

“I’m excited about the projects that we will be working on over the next few months. Trypanosomiasis will be a new pathogen for me to understand in my field of zoonotic diseases and I am glad that collaborations were encouraged, but that this was not a necessary component. However, I do feel that the collaboration will lead to much longer communication among group members and create further contacts for future collaborative work. I also like that my group does have an African student in a mix of American students. We hope to produce a manuscript from our research project in the future.

“I would like to see where each of the students embark after working on their projects for six months. If there is an opportunity for a reunion of some sort, that would be fantastic. Living together, eating, and learning together at AIMS really created strong friendships over the two weeks. I think it was a great idea to open up the workshop to both US and African students...

“The capstone workshop was also great. There were more opportunities to meet new people in the field of mathematical epidemiology and listen to what they work on and what they have found with their research. I hope to see these individuals at future meetings relating to disease ecology.” Holly Vuong, Rutgers University

“My experience at the advanced study institute in South Africa has given me the initiative to model the spread of infectious diseases that specifically affect the African continent. The opportunity of working with other students from all over Africa proved invaluable. I gained a different perspective on how to approach problems that directly impinge on communities in Africa. Having the institute in South Africa gave me a greater appreciation for the resources that I have been afforded at my home institution. I now have a responsibility to collaborate with my fellow students in Africa, so that we together can make a difference through research. At the short course I gained insight to so many different topics like graph theory, optimal control, and stochastic processes, and how these ideas can be applied to modeling infectious diseases. The faculty lecturers were phenomenal, and they gave very good direction for all of the students’ research topics. The overall experience was very enlightening, and I hope to work on a HIV project that can directly make a difference in Africa.” Danielle Robbins, Arizona State University

“The workshop opened many research opportunities that I did not think of before. At moment, My advisor and I are looking forward in developing an HIV/AIDS model that will include other factors that enhance the spread of the disease apart from those discussed at the workshop. I made many connections with the professors. I was very amazed with Prof. Lungu Edward’s talk how the cultures in Africa expedite the spread of the disease. I never thought such weird cultures existed.

“I am so grateful for Dimacs, AIMS, SECEMA and most of all NSF for giving me the opportunity to attend the workshop and conference. I wanted to be a teacher after my PhD but now I have completely

changed my mind and will do more research than teaching.” Akongnwi Clement Mformbele, Lehigh University

“The two weeks institute at AIMS in Muizenburg was very educating and informative, to say the least. I had the opportunity to meet with and study together with other students from various science and cultural backgrounds about mathematical modeling of infectious diseases especially as it affects sub-Saharan Africa. The high point of the two weeks period was the collaborative effort between African and American students in the project work. Every member of the group for the project contributed maximally as we all brain-stormed to write the project proposal with all the mathematical equations. Our project is about modeling the impact of TB on HIV with optimal control. Similarly, the follow up workshop at Stellenbosch was the crown of it all. As I listened to different speakers give lectures on different applications of infectious disease modeling gave me a deeper understanding of the subject of infectious disease modeling. Personally, as a workshop note-taker, I had the added privilege of a closer knowledge of the different subjects. I pray such initiatives and opportunities will be open to more diverse students in the future.” Anthony Ogbuka, Morgan State University

“The Advanced Study Institute was a great experience. For me, being the only epidemiology student in attendance, it strengthened my math skills and gave me a better appreciation for the math involved in this type of modeling. I have also greatly benefited from contact with the instructors and conference presenters. I came to ASI with an idea of what I want to work on, but didn't know how to get started. Now I have a solid research question and direction on how to proceed. I plan to expand on my ASI project for my dissertation. It was also valuable to collaborate with the other students at ASI, particularly with the African students, two of which are in my group.” Sarah Radke, University of North Carolina

“This was an amazing experience, in terms of meeting people (both fellow students and lecturers) that are doing things that I am interested in... Where I am, it is rare that I would amass such a rich experience.” Sourya Shrestha, University of Michigan

Many students specifically said that meeting students from other countries and meeting researchers in the field were high points of the program. In answer to the question on the exit questionnaire “What have you enjoyed the most” the replies included “meeting students from Africa and the US. Not only have I learned a lot about epi modeling, I've also had the opportunity to learn about the African culture,” “interacting with students from many countries,” “mixing with others, meeting a lot of profs,” “interacting with other students from US and Africa,” “meeting people from different backgrounds and regions,” “the level of learning and the interaction/group work with other creative minds,” “talking to people from all over the world was the best,” “interactions with everybody,” “meeting new people, networking, and experiencing a new academic environment,” “interactions with other students and lecturers,” “meeting other black mathematicians from Africa and learning with them,” “interactions with scientists,” “student to student interactions.”

Students recognized the value of this early start to establishing multidisciplinary and international collaborations. It will “help me advance my thesis research and hone ability to work in a multidisciplinary team.” “It will give me valuable collaborators for future research and has broadened my understanding of how epi modeling fits into the social disciplines.” “This institute will impact me by reminding me of the importance of working with people.” “It has helped me to create a network and possibly find a thesis topic.”

Students saw their participation has having a direct impact on their research programs for their degrees. “It will help me to find new problems that can be Ph.D. problems and of course it helps me to find a supervisor.” “I will be using some of the modeling in my Ph.D. work on general disease dynamics.” “It has helped me discover a new topic of math to study in grad school.” “I now have a dissertation and thesis

ideas and motivation to continue learning mathematics.” “This will help me streamline my studies towards topics in modeling.” This has “helped me to continue with my Ph.D. dissertation; (I) have been motivated.”

The Institute was structured so that students worked with models and developed their own research projects, building their confidence in their own abilities. “This has made me realize how I can apply what I learned in courses to my research. I also realized that I know more than I thought I knew.” “The Institute helped me get a good foundation on modeling systems and I feel more confident about modeling.” “Now I have a good direction; I feel well equipped with epidemiological and math background.” “I will be able to explore other areas of research especially in epidemiology.” This “confirmed the need for math modeling techniques to explore research questions of interest. Also (this) gave me enough background to start diving in and learning more on my own.”

Outreach Activities

Ashley Crump, the only undergraduate student accepted to attend ASI, addressed the workshop during the discussion on next steps about the need to get other students, math and non-math majors alike, to learn more about the use of mathematics in addressing some real life problems. Ashley would like to reach out to other undergraduates and to high school students about her experiences in this program. Ashley described her experience as follows:

“I definitely think that the workshop met its goal of increasing international collaborations. I believe that most student research groups consist of both African and American students, so we are working together to solve problems that influence the world. As an undergraduate student, this workshop helped me to realize that math is being used everyday by governments all over the world to solve real life problems. I had heard of applied mathematics, but I never really understood how big of an impact mathematicians could have on the world. After listening to only one lecture I was shocked to learn that disease is the number one killer on the continent of Africa. I compared the top killers of Africa to the top killers in the United States and I was able to realize how different things really are. After talking with students from Africa I was able to learn about the different cultures of so many African countries. Because some of the material may have been a little advanced for an undergraduate student, I feel that I learned more outside of the classroom than during lectures. Either way, this was a life changing experience and has impacted me so greatly that I will try even harder to earn a PhD in applied mathematics so that I can help solve problems like so many of the students, professors, and other workshop participants are now.” Ashley Crump, Howard University

The African students also realized the importance of sharing what they have learned when they return to their home institutions. They understand that they will be able to make an impact on their countries.

“I have started to spread the news in my country to my friends that we can use mathematics to solve the problems of diseases.” Theresia Marijani, University of Stellenbosch

Books

A select group of students from the Advance Study Institute were recruited to write lecture notes from the Institute. We plan on publishing these lecture notes as a volume in the DIMACS Book Series published by the American Mathematical Society.

Papers

We expect that most of the projects begun by the students in the Advanced Study Institute will result in papers. In addition, we expect papers as a result of the new collaborations between researchers that were begun during the workshop.

Talks

We expect that many of the students working on projects begun in the Advanced Study Institute will present their results at both professional conferences and seminars at their home institutions. Researchers will be presenting the results of the collaborations begun during the workshop.

Other Specific Products

Reports

Anthony A. Ogbuka and Devroy O. McFarlane, *DIMACS/SACEMA/AIMS Workshop on Mathematical Modeling of Infectious Diseases in Africa*, in preparation.

Web pages

<http://dimacs.rutgers.edu/Workshops/AIMS/>

Main web page for US-Africa Advanced Study Institute on Mathematical Modeling of Infectious Diseases in Africa

<http://dimacs.rutgers.edu/Workshops/AfricaDiseases/>

Main web page for DIMACS Workshop on Mathematical Modeling of Infectious Diseases in Africa

Contributions

Contributions within Discipline

“I was an instructor at the ASI and presented recent research at the workshop. The ASI provided me with excellent professional experience in the opportunity to teach a large and diverse group of graduate students. As a postdoctoral fellow I have not yet had this opportunity in a formal setting, and benefited from the interactive environment of the ASI as well as the mid-course feedback. Interactions with the students were stimulating and fruitful, and I am optimistic that several of the ASI projects that I am advising will lead to published work. In particular there is one promising project examining the influence of urban vs rural differences in healthcare delivery on the development of TB drug resistance, and another on the possible indirect effects of a partially protective malaria vaccine. Interactions with fellow ASI faculty were also very stimulating, and I discussed the possibility of future collaborations with each of Wayne Getz, Jonathan Dushoff and Abba Gumel.” James O. Lloyd-Smith, CIDD Postdoctoral Scholar, Center for Infectious Disease Dynamics, Penn State University

“I met with John Hargrove, and have already begun establishing a link between SACEMA and IIASA (<http://iiasa.ac.at/>) that would extend the work of our conference.” Simon Levin, Princeton University

Contributions to Other Disciplines

This was a cross disciplinary project. The students at the Advanced Study Institute came from Biology, Biomathematics, Biomedical Engineering, Ecology, and Epidemiology as well as Computational Science, Computer Science, Mathematics, Physics, Statistics, Public Health. The presentations in the capstone

workshop covered biology, mathematics, and economics as applied to the mathematical modeling of the spread and impact of infectious diseases.

Contributions beyond Science and Engineering

A strong theme of both the Advanced Study Institute and the capstone workshop was the use of the results of mathematical modeling by public health officials. Several participants commented on this.

“I think with these skills I am optimistic that we will be able to create an appropriate model and use both analytical and computational tools to provide insight for public health policy makers to make decisions and for field scientists to gather appropriate data.” Steven Bellan, UC Berkeley

“After the training, I communicated the idea of modelling and its application to my two health professional colleagues and my supervisor in school of public health, University of Western Cape. After the discussion with my supervisor, my department was willing to increase further collaboration with SACEMA, and we have made appointment for a meeting in mid August to discuss how we can increase collaboration.

“My comment during the training relates with the fact that many of the participants were from Mathematics and biology background, and only two of us were the only public health personnels. In the future, we might comeout with more interesting works if the collaboration between modellers and public health personnels can be strengthened. For instance, I am from pure public health background and to me combining Public health with Maths and statistics is the most satisfying career. I am doing my final year masters and my PhD on modelling. This is the most creative thing I ever seen in history of public health. I hope you will increase the chance given to public health personnels in the future trainings.” Selamawit Woldesenbet, University of Western Cape

Contributions to Human Resources Development

We expect that one of the outcomes of this project will be the incorporation of material specific to infectious diseases in Africa in the course material of the US faculty participants. We also expect that participation in this project will have a profound effect on the future teaching of the students. Below is a comment from one of the African students to this effect.

“It has helped me get a good grasp of the issues involved in epidemiology. This will help me with future research and teaching.” Kyle Tomlinson, University of KwaZulu Natal