Collaborative opportunity to leverage network infrastructure in the southern hemisphere between Africa, Brazil, and the U.S.

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Abstract

Linking South and North America via a South Atlantic high-performance Research & Education Network (REN) with the researchers, students, and knowledge sharing communities of the nations of Africa has become an increasingly strategic priority. Africa offers research and education communities with unique biological, environmental, geological, anthropological and cultural resources. Research challenges in atmospheric and earth sciences, materials sciences, tropical diseases, biology, astronomy and other disciplines will benefit by enhancing the technological and social connections between the research and education communities of the U.S., Brazil / Latin America and Africa. For many years, we have seen the dramatic benefits of high-performance networking in all areas of science and engineering.

The Americas Africa Research and eduCation Lightpaths (AARCLight) project (NSF OAC-1638990) provided support for a grant to plan, design, and define a strategy for high-capacity research and education network connectivity between the U.S. and West, Central and Southern Africa. The study indicated a high level of enthusiasm to engage in collaborative research between the U.S., Brazil, and the African communities. There is collaborative interest in sharing network infrastructure resources in the US at AMPATH in Miami, in Fortaleza and São Paulo, Brazil where RedClara and ANSP connect at SouthernLight exchange points, and in Cape Town, South Africa. There is strong evidence of multiple ongoing domain science projects between the U.S., Brazil, and Africa that would benefit from a new South Atlantic link. The results of this planning grant successfully supported the need to light a 100G pathway using the South Atlantic Cable System (SACS) connecting to AmLight-ExP in Fortaleza, Brazil, and via the West African Cable System (WACS) cable to the ZAOXI open exchange point at Cape Town, South Africa.

Based on these findings, AmLight-ExP, a high-performance R&E network supported by a consortium of participants and funding from the NSF is the steward of the SACS 100G link. With collaborative support from UbuntuNet Alliance, RNP, TENET/SANReN, and others, AmLight is taking steps to make this first South Atlantic R&E network path available to connect all three continents.
The paper presents 1) the key partners in the AmLight-SACS collaboration, 2) the technological background, 3) the activation plan, and how the network will be instrumented for performance measurements, and to capture data for network analytics, and 4) science drivers that will benefit from the use of a South Atlantic network route between the U.S., South America and West, Central and Southern Africa.

Keywords
Collaboration, Cyberinfrastructure, Network, USA, Brazil, Africa

1. The Collaboration Partners

The partners in this collaboration are AmLight-ExP (USA), RNP (Brazil), TENET/SANReN (South Africa), UbuntuNet (Africa), WACREN (Africa), and Angola Cables.

AmLight Express and Protect (ExP) (Ibarra, Morgan and Cox, 2015) implements a hybrid network strategy that combines optical spectrum (Express) and leased capacity (Protect) that builds a reliable, leading-edge diverse network infrastructure for RENs (research and education networks). AmLight ExP operates high-performance network links connecting Latin America to the U.S., funded by the National Science Foundation (NSF award #ACI1451018), together with significant contributions from RNP, the Brazilian national REN, and ANSP, the statewide REN of the state of São Paulo (ANSP), in addition to AURA (the Association of Universities for Research in Astronomy), the total bandwidth provided by AmLight-ExP between the U.S. and South America is expected to grow to more than 680 Gb/s in aggregate capacity between 2015 and 2020.

RNP is installing and will operate SAX, (South America eXchange point) a Global Exchange Point for RENs (GXP) in Fortaleza, Brazil, as an open exchange point for Research & Education Networks. SAX will provide an optimal geographic location for exchanging traffic between Europe, Africa, and the Americas. Traffic on the Monet and SACS subsea cables will be routed to Africa via SAX. RNP's capital investment in SAX thus far has been approximately $200,000, accompanied by ongoing OA&M expenses.

The South African National Research Network (SANReN) and the Tertiary Education and Research Network of South Africa (TENET), jointly form the South Africa's NREN. TENET is South Africa's national REN organization. SANReN is a business unit inside the South African CSIR's Meraka Institute and is responsible for the design, acquisition and roll-out of national and international capacity for the South Africa NREN, as well as the development and incubation of advanced services. TENET operates the SANReN network, which is a key component of the South African government's National Integrated Cyberinfrastructure System (NICIS), alongside the Centre for High Performance Computing (CHPC) and the Data Intensive Research Initiative of South Africa (DIRISA). TENET/SANReN has ownership of 7.4% of the WACS cable, between South Africa and Europe) allowing it to light capacity between any 2 landing stations. TENET/SANReN operates the ZAOXI GXP in Cape Town and will activate a 100G wave from Cape Town to Angola, to interconnect with the SACS cable.

UbuntuNet Alliance is a regional REN in eastern and southern Africa, that works with its

member NRENs, and coordinates and collaborates with peer regional RENs, such as GEANT and RedCLARA. The UbuntuNet Alliance seeks to extend the capacity and resilience of its regional backbone network, UbuntuNet, with high-capacity connections to RENs worldwide and to the commercial Internet.

West and Central African Research and Education Network (WACREN) is a regional REN serving the West and Central African R&E community for its development. One of the main goals of WACREN is to interconnect NRENs and peer institutions at continental and international levels.

Angola Cables (AC) is a network operator which owns a third of the MONET cable system (Rodrigues, 2018b), as well as 100% of the SACS cable (Rodrigues, 2018a), and has activated a direct optical connection between the SACS and MONET cables (Qiu, 2019). Angola Cables is also part of the WACS consortium, comprised of 14 companies. WACS has 15 landing points between South Africa and Europe (*West Africa Cable System (WACS) technically goes live, benefits soon to follow*, 2012). AC also managing two data centers: AngoNAP Luanda in Angola and AngoNAP Fortaleza in Brazil, as well as Angonix, located in Luanda, one of Africa's top five Internet Exchange Points.

2. Background

The partners in this collaboration are AmLight-ExP (USA), RNP (Brazil), TENET/SANReN (South Africa), UbuntuNet (Africa), WACREN (Africa), and Angola Cables.

A key finding of the AARCLight Planning Grant (Ibarra *et al.*, 2016) funded by the NSF (NSF #ACI1638990) to Florida International University and University of Southern California is the opportunity to leverage network infrastructure in the southern hemisphere that is available to the R&E community:

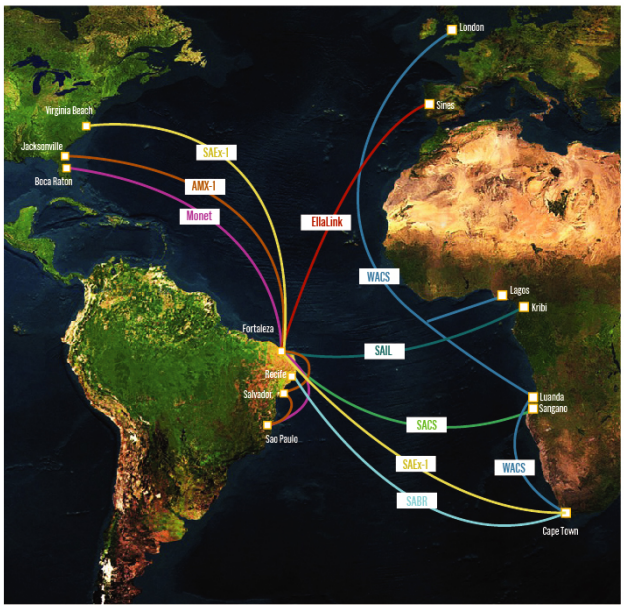

Figure 1 Modern submarine cables in the South Atlantic

- 225GHz of spectrum on Monet is committed to the AmLight-ExP project, providing Nx100G links between Miami, Fortaleza and São Paulo;
- 40GHz of spectrum on the South Atlantic Cable System (SACS) is available to the research and education (R&E) community, currently providing a 100G Ethernet link;
- TENET/SANReN together operate more than 800Gb/s of the capacity on WACS, a fraction of which may be used to connect to SACS in Sangano, Angola
- The ZAOXI R&E exchange point in Cape Town operated by TENET/SANReN is connected to the West African Cable System (WACS) and the Ubuntunet Alliance Network connecting East Africa;
- The SAX (South America eXchange) R&E exchange point in Fortaleza, operated by RNP and connected via AmLight-ExP via Monet to São Paulo and Florida.

Based on the available cyberinfrastructure, we can activate 100G Ethernet in 2019 on SACS

to establish a new South Atlantic route connecting Africa, Brazil and the US, referred to as AmLight-SACS. AmLight-SACS will integrate with the AmLight Express and Protect (AmLight-ExP) path, adding resiliency to the global R&E network fabric by adding a new path to Africa and Europe from the southern hemisphere.

The SACS cable, shown on Figure 2 as a purple dashed line between Fortaleza, Brazil, and Luanda, Angola, is the first east - west subsea cable in the South Atlantic of the Internet Age.

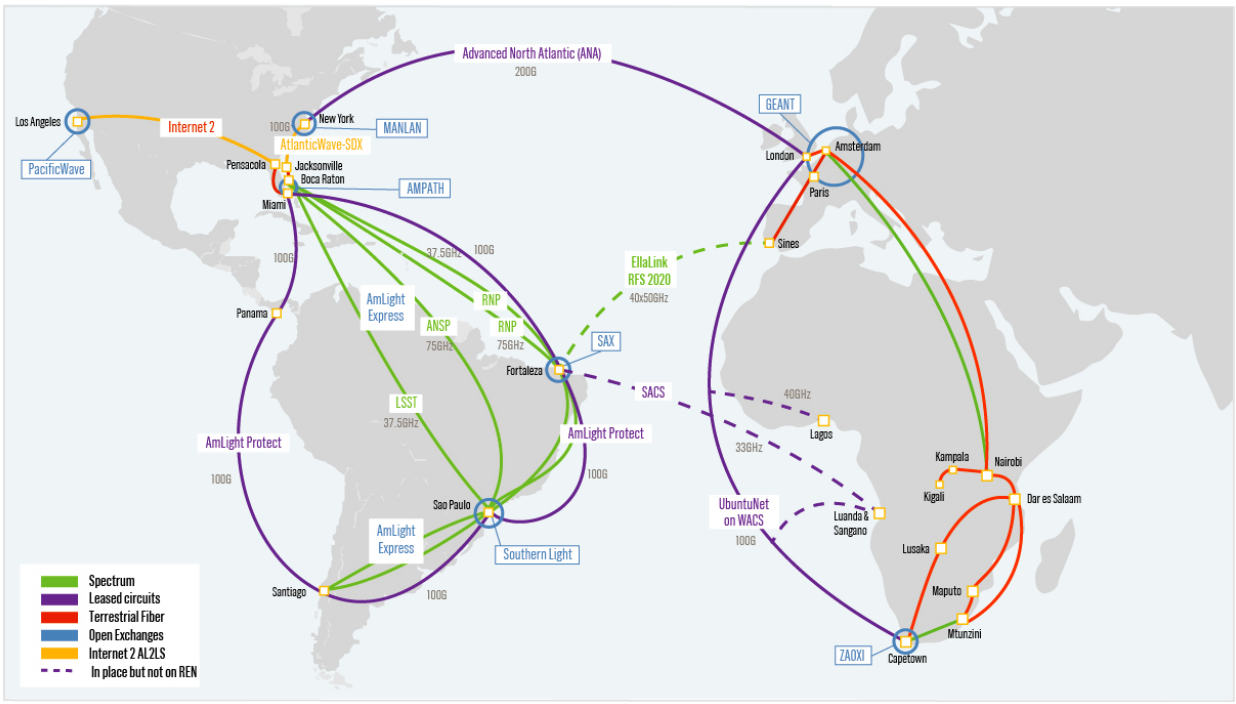

Figure 2 R&E network backbone links across the North and South Atlantic

This paper describes the leveraging of network infrastructure in the Southern Hemisphere that is available to the Collaboration Partners described in Section 1. The available transmission resources include capacity on (1) the Monet cable committed to the AmLight-ExP collaboration, linking Miami, Fortaleza and São Paulo, (2) the SACS cable between Fortaleza and Luanda, Angola, and (3) the WACS cable between Luanda and Cape Town, South Africa. The global R&E exchange points (GXP) involved are located in Miami (AMPATH), Fortaleza (SAX) and Cape Town (ZAOXI), operated respectively by CIARA, RNP and TENET/SANReN. (South African National Research Network) , the South America eXchange R&E exchange point (SAX) in Fortaleza, operated by RNP and connected via AmLight-ExP on Monet to Boca Raton and Miami, Florida at the AMPATH (Ibarra, Clark and Morgan, 2015) Open Exchange Point(s).

Table 1 shows latency measurements taken from the TENET network in Cape Town, traversing research networks UbuntuNet, GEANT, Internet2, AmLight, RNP and REUNA. SACS cable measurements from Angola Cables The comparison shows a notable difference from the use of the SACS cable.

From Cape Town to:	Formerly via TENET, UbuntuNet, GEANT, and I2	Actually via SACS	Possible Improvement
New York	241ms	192ms	126%
Miami	272ms	161ms	169%
Fortaleza, Brazil	336ms	97ms	346%
Sao Paulo, Brazil	381ms	142ms	268%
Santiago, Chile	382ms	143ms	250%
La Serena, Chile	392ms	153ms	256%

Table 1 Latency measurements taken from the TENET network in Cape Town and via SACS

3. Activation Plan

Activating the spectrum on SACS, and then interconnecting SACS to both the WACS and Monet cables will allow an express connection between Africa and the U.S. via Brazil, as shown in Figure 3. Additionally, the global R&E network fabric can be strengthened from the additional pathways through the Southern Hemisphere.

The spectrum on the SACS and Monet subsea cable systems will be available for use by the R&E community for at least 25 years. As transponder and transceiver technology advances to provide higher bandwidth capacities, it will only be necessary to upgrade the transponders and transceivers - a one-time equipment cost.

Figure 3 shows the active equipment to activate the SACS subsea cable system and to interconnect it with WACS and Monet. Through a supplemental funding proposal to the NSF (AmLight-SACS) FIU has purchased two 100G transponders (shown in green in Figure 3), native to the SACS cable systems. One 100G transponder is deployed in Fortaleza, and the other in Sangano, Angola. The solution leverages network infrastructure resources provided by partners RNP (blue), SANReN/TENET (red), FIU and Angola Cables (black). Figure 3 represents three subsea cable systems: Monet, SACS and WACS. Once the active equipment in green is deployed and the 100G wave on SACS is activated, RNP will provide a connection on its Ethernet switch in the SAX-GXP (purple LR4 to green LR4), and interconnect SACS and Monet across its switch fabric, extended to AMPATH in Miami. Likewise, at the cable landing station in Sangano Angola, Angola Cables will directly connect the 100G transponder (green) to its 100G transponder (black), creating a physical connection into the WACS optical system, and extending the optical circuit to its transponder in Cape Town. In the WACS Data Center, Angola Cables will hand off the 100G circuit from its LR4 transceiver (black) to the ethernet switch in the ZAOXI Global Exchange Point (GXP).

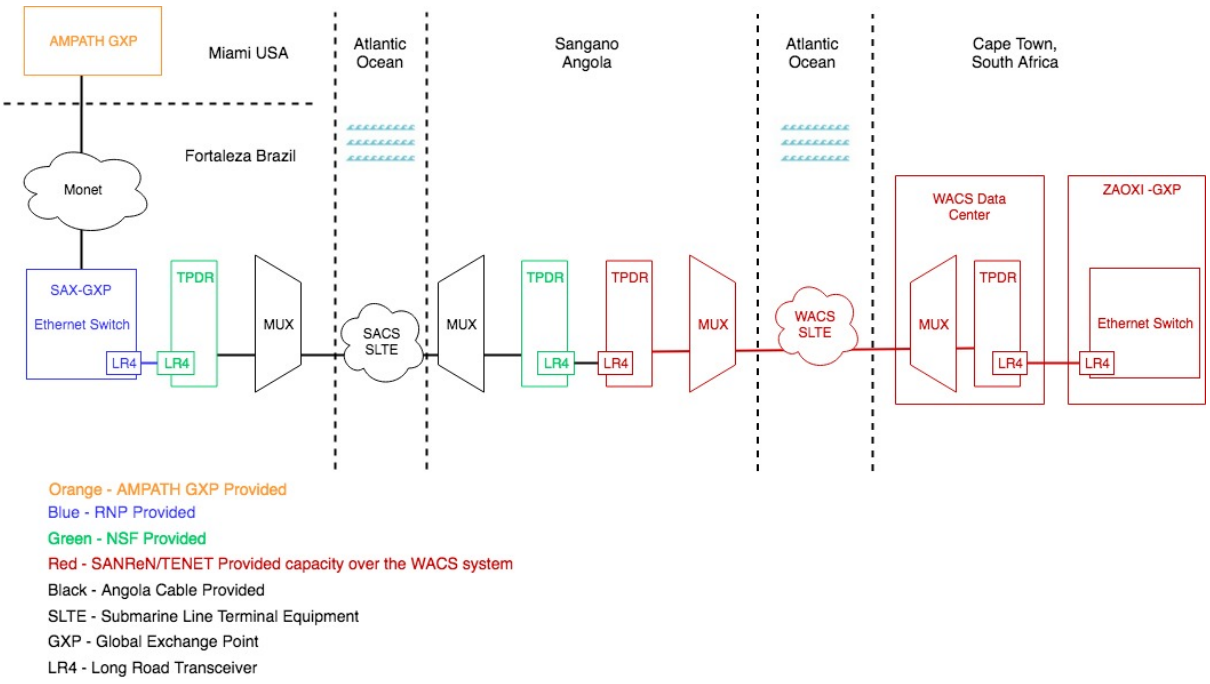

Figure 3 Components for the activation of the SACS subsea cable system

3.1 Instrumentation of the AmLight-SACS network

To measure science flows and network traffic on the AmLight-SACS network, network measurement instrumentation shall be deployed at the following global R&E open exchange points: ZAOXI in Cape Town South Africa, South Atlantic Crossing (SAX) in Fortaleza, and AMPATH in Miami. AndesLight in Santiago Chile was added to represent the AmLight-SACS 100G link in relation to the AmLight ExP ring (300G along the Atlantic, and 100G along the Pacific and Andes). Figure 4 is a representation of the monitoring and measurement instrumentation for the AmLight-SACS network. perfSONAR (pS) shall be used to monitor the status of the network at each of the GXP exchange points. The perfSONAR MADDash in operation at AMPATH will be used to represent the state of the AmLight-SACS link.

IP flow data across the AmLight-SACS link shall be collected. The AMPATH Network Management System (AMPATH NMS) runs a NetFlow collector. IP flow data between the U.S. and Africa using the AmLight-SACS link will be collected at AMPATH for analysis. The AMPATH NMS will export NetFlow data to NetSage, in the same way it exports IP flow data from the AmLight-ExP links. AMPATH and SouthernLight GXPs are registered with the RouteViews collector. Routing data will be gathered with RouteViews for analysis and representation of the routing topology involving AmLight-SACS.

Measurement data collected on AmLight-SACS will be provided to the NetSage (Gonzalez *et al.*, 2016) team, along with other measurement data gathered from other AmLight backbone links. If consent from science communities is required to capture NetFlow data to monitor and better understand performance of these international flows, an additional talk to the appropriate scientists about measuring performance of their flows can help them understand the benefits that may be achieved to improve the time it takes for data transfer rates and volumes.

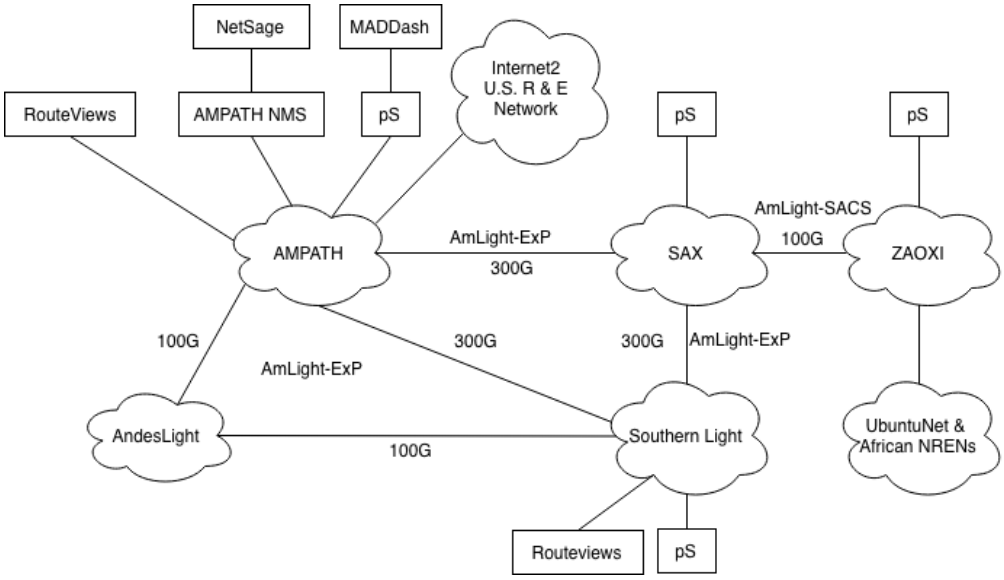

Figure 4 Monitoring and Measurement Instrumentation of the AmLight-SACS network

4. Science drivers

Multiple ongoing collaborative projects between the researchers from the U.S., Brazil and African communities can potentially benefit from the network connections in the South Atlantic. This section describes a few of the major projects involving cyberinfrastructure, astronomy, medical and genomics research.

4.1 Astronomical Sciences (AST)

The South African Radio Astronomy Observatory (SARAO) is a National Facility managed by the National Research Foundation (NRF) (Bank, 1990) and incorporates all national radio astronomy telescopes and programs.

Figure 5 Telescope sites across Africa, with its core in the Northern Cape

The South African Astronomical Observatory (SAAO) is another facility of the National Research Foundation (NRF) (Walker, 1986), which operates optical telescopes, outreach and research located in Sutherland under the Department of Science and Technology. The Southern African Large Telescope (SALT) (Stobie, Meiring and Buckley, 2000) is the largest single optical telescope in the southern hemisphere and among the largest in the world managed by SAAO. SALT is funded by a consortium of international partners from South Africa, the U.S., Germany, Poland, India, the U.K., and New Zealand. Other SAAO Hosted Research Telescopes are Birmingham Solar Oscillations Network (BiSON) (Chaplin *et al.*, 1996), KELT-South (Pepper *et al.*, 2012), Las Cumbres Observatory (LCOGT) (Brown *et al.*, 2013), a MOnitoring NEtwork of Telescopes (MONET) (Hessman, 2001), Solaris (Kozłowski *et al.*, 2017), and SuperWASP-South (Lister, Anderson and West, 2007). SAAO has remote telescopes that require enough bandwidth for US based PIs to operate (e. g., Ted Williams, US remote observer). The demand

for remote observing is increasing because of transient (LSST) and gravitational wave (LIGO, VIRGO, IPTA, LISA) ground-based follow-up. Currently operating with 35 Mb/s international (budget for bandwidth is $500k/year).

The MeerKAT 64-antenna array radio telescope located in the Karoo region is a precursor to the Square Kilometre Array (SKA) (Davidson, 2012) and will be merged into the SKA1 (2020). The MeerKAT collaboration has chosen 8 PIs for a guaranteed 2/3 of the observing time for the telescope's first phase of observing before SKA integration. The other 1/3 of time is allotted to general observers, and the call for proposals is open to US scientists. MeerKAT will have a data archive (MeerKAT Mirror) that will be publicly released in 2020, and the collaboration currently developing a plan for how to manage the archive and queries for data as well as transfer. The MeerKAT current data rate is 3.5 Gbps.

SKA High frequency dishes will produce ten times the current global internet traffic and generate 960,000 Tb/day with rate of ~160 Gb/s made up of 109 bps from each radio dish to a central processor. SKA will be the largest array telescope in the southern hemisphere with collaborators from USA, Canada, India, Japan, China, Australia, France, UK, Italy, Finland, Germany. SKA Phase two will include telescopes from New Zealand, Botswana, Ghana, Kenya, Mauritius, Madagascar, Mozambique, Namibia and Zambia.

The SKA will be fully operational in 2022 and the data will be piped out to regional science data centers, using data cubes to handle large amounts of data. Some of the scientists want to do their data processing in Cape Town and some in their countries (Netherlands and India may want data in their countries). Canada has a SKA center designation. A 100G link minimum is targeted for all SKA1 data transfer.

> "*With SKA's presence in South Africa, a larger astro research presence will begin to take root in the region that will demand access to the global treasure-trove of data currently generated by six telescopes supported by the U.S. National Science Foundation, and complementary instrumentation, such as the Murchison Widefield Array (MWA), a precursor to SKA, in Western Australia at the Murchison Radio-astronomy Observatory (MRO)"* (Leake, 2018).

The Hydrogen Epoch of Reionization Array (HERA) (DeBoer *et al.*, 2017) is an NSF funded experiment (NSF awards #1440343, 1636646) currently in operation. HERA is a radio telescope dedicated to observing large-scale structure during and prior to the epoch of reionization. HERA is a second-generation instrument, which combines efforts and lessons learned from the Murchison Widefield Array (MWA) (Wayth *et al.*, 2018) and the Donald C. Backer Precision Array for Probing the Epoch of Reionization (PAPER) (Backer, 2009). PAPER is a Phase-I HERA activity that is investigating key elements of the road map such as antenna design, array configuration, data storage, correlation and signal processing for large-N arrays, calibration, and interference mitigation techniques. Phase-II of HERA entails applying lessons learned during Phase I to define and build a larger array. The final stage of HERA, Phase III, will address the challenges of full tomographic imaging using a Square-Kilometer-Array-scale facility with capabilities informed by the earlier work. HERA project produces ~1.5-2 TB/day but current infrastructure only supports 200 Mbps. The HERA collaboration relies on shipping tapes.

4.2 Biological Sciences (BIO)

Sensor networks in local, regional, and international networks, involved in molecular biology, has resulted in increased need for bandwidth. To support the extra connectivity the field stations and the remote facilities need networks that will allow scientists to share best practices, protocols, and platforms for data archiving and retrieval (McNulty *et al.*, 2017).

Region	Numbers of BFS
Africa	116
Antartica	82
Asia	185
Canada	82
Caribbean	19
Central America	83
Europe	241
Greenland	2
Latin America	88
Oceania	62
USA	308
Grand Total	1268

Figure 6 Biological field stations per region

The Organization of Biological Field Stations (OBFS) is an organization that represents field stations, marine labs, and research centers (Brunt and Michener, 2009). Many field stations appear to be located in South America, the Caribbean, and west Africa (Tydecks *et al.*, 2016), see Figure 6. Several collaborative projects are taking place in South Africa (Kruger National Park), West Africa (Mozambique), and Central Africa (Democratic Republic of Congo). JetStream cloud project adds cloud-based, on-demand computing and data analysis resources to the national cyberinfrastructure (Stewart *et al.*, 2015) and supports the outreach to the biological field stations and marine labs for access to cloud services. Africa has 116 biological field stations.

Additional future collaborative projects have been identified among the Brazilian Research and Educational Network (RNP) applications. RNP supports many science drivers complimentary to collaboration with African research interests. An agricultural collaborative research involving pest control on army worm (*lagarta do cartucho*) attacking maize and sorghum, is conducted between Brazil, U.S., South Africa, and nine other African countries and supported by Embrapa (Brazilian Corporation for Agricultural Research in the Ministry of Agriculture). Multiple ongoing collaborative medical projects with the African nations of the Community of Portuguese -Speaking Countries (CPLP) are established by the Brazilian Ministry of Health - Osvaldo Cruz Institute (FIOCRUZ) (Minayo *et al.*, 1998) in collaborations with the National Institute of Infectiology in Mozambique on clinical research and clinical tests. CPLP consists of the following countries: African countries: Angola, Cape Verde, Equatorial Guinea, Guinea-Bissau, Mozambique, and São Tomé and Príncipe. Non-African full members: Brazil, Portugal, and Timor-Leste. The scope of those projects includes infectious diseases, such as Malaria, STI, AIDS, Viral Hepatitis, and Tuberculosis. Another FIOCRUZ and Federal University of Rio de Janeiro (UFRJ) project in Angola is collaborating with the National Institute for Health Research (NIHR) of the Angolan Ministry of Health de Angola, currently investigating the genotyping and resistance of HIV-1 to anti-retroviral drugs.

The Atlantic International Research Centre (AIR-Centre) has agreements between the EU-BR-ZA for collaborative research activities in the South Atlantic and Southern Oceans The ambition of the AIR Centre is to be a long-term platform for North-South, South-North, East-West and West-East collaboration in the Atlantic towards a holistic, integrative and systemic approach to knowledge on space, oceans, climate change impacts, energy and data sciences, while fostering an inclusive perspective to science, technology and economic development (Rojas *et al.*, 2017).
Mozambique NREN (MoRENeT) has a long-standing collaboration with RNP participating annually in the RNP Forum since 2014. Activities include exchange of good practices in management and governance of research networks, IT training (including 25 techies in 2017 in Brazil), and exchange of information on technical and operational management.

4.3 Earth Sciences

Seismic and geodetic facilities are geographically dispersed, and they manage and support continuous observations from distributed sensor packages. UNAVCO (Rocken *et al.*, 1995) and Incorporated Research Institutions for Seismology (IRIS) (Smith, 1986) are the two organizations that support the geosciences facilities worldwide. UNAVCO manages thousands of GPS sites. IRIS is a consortium of 121 US universities and 123 International members and dedicated to the operation of science facilities for the acquisition, management, and distribution of seismological data.

Also, research projects involving the expansion of the AfricaArray (AA) Seismic Network (Dirks *et al.*, 2009) with continuous Global Positioning System (CGPS) instruments fitted with meteorological (met) sensors by UNAVCO/Penn State University and AA creates a multidisciplinary research network for the broader Earth science community. AfricaArray Seismic Network participate with a total of 53 stations in 17 countries (Raveloson, 2017): 29 seismic only stations; 20 collocated seismic, GPS, and weather stations; 2 collocated GPS, weather; 1 collocated seismic, GPS; and 1 weather only station.

4.4 International and Integrative Activities

Several activities involving Sub Saharan Africa have potential benefits to the global research community. In the InCommon/eduGain project report (Leake, 2018), the African regional-serving universities benefit from fast and affordable bandwidth delivered via NRENs that engage with larger networks, such as the UbuntuNet, and WACREN, to deliver more advanced service options. The major networks then peer with Internet2 in the U.S. and GÉANT in Europe.

Another international integrating activities led by Steve Huter at the Network Startup Recourse Center (NSRC) University of Oregon (Wenzel, Klensin and Huter, 1996) promotes collaboration among a community of peers to build and improve the global Internet that benefits all parties. The center facilitates the growth of sustainable Internet infrastructure via technical training and engineering assistance to enrich the network of networks.

4.5 Medical Research and Genomics

Several NIH major collaborative projects in the area of infectious disease control and prevention in Africa would benefit from the use of the AmLight-SACS network for access to CI resources in the U.S. In addition to those projects, NIH HIV/AIDS clinical trial projects are involved with several trial network groups that are identified in the USA and Africa. See Appendix A.

There is significant number of NIH sponsored projects all over Africa that are dependent on connectivity for data transfers back to the U.S., as shown on Figure 7. These transfers are becoming more substantial as the use of genomic data and imaging data becomes more widespread.

Figure 7 NIH Projects in Africa. Source: https://report.nih.gov/award/#tab4

The United States Army Medical Research Directorate Kenya (USAMRD-K) is another collaborative initiative between NIH and African medical research communities. USAMRU-K is located in Nairobi, Kenya on the campus of the Kenya Medical Research Institute (KEMRI) and is one of five U.S. DoD overseas research laboratories. The USAMRU-K Kisumu Field Station is based in Kisumu, Kenya located in Nyanza Province along Lake Victoria. There are five clinic and research departments to include Clinical Trials, Basic Science, Malaria Diagnostics Center (MDC), Entomology/Vector Biology Unit, and Malaria Drug Resistance (MDR) Laboratory. The focus of this program is to develop drugs and vaccines for malaria and other tropical diseases.
The KEMRI Welcome Trust Research Program (KWTRP) is based within the KEMRI Centre for Geographic Medical Research. The core activities are funded by the Welcome Trust and include conducting integrated epidemiological, social, laboratory and clinical research in parallel, with results feeding into local and international health policy. This research platform includes state-of-the-art laboratories, a demographic surveillance system covering a quarter of a million residents, partnership with Kilifi County Hospital in health care and hospital surveillance, a clinical trials facility, a vibrant community engagement program and a dedicated training facility.

Another genomics and bioinformatics project called Human Health and Heredity (H3 Africa) facilitates fundamental research into diseases on the African continent (Osafo *et al.*, 2015) while also developing infrastructure, resources, training, and ethical guidelines to support a sustainable African research enterprise - led by African scientists, for the African people. The initiative consists of 48 African projects, see Figure 8, that include population-based genomic studies of common, non-communicable disorders such as heart and renal disease, as well as communicable diseases such as tuberculosis. These studies are led by African scientists and use genetic, clinical, and epidemiologic methods to identify hereditary and environmental contributions to health and disease. To establish a foundation for African scientists to continue this essential work into the future work, the consortium also supports many crucial capacity building elements, such as: ethical, legal, and social implications research; training and capacity building for bioinformatics; capacity for biobanking; and coordination and networking (Nordling, 2017).

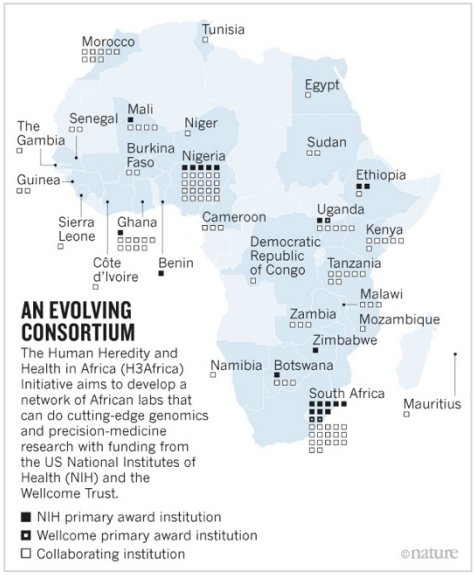

Figure 8 Human Heredity and Health in Africa (H3Africa) projects in Africa

5. Conclusion

Activating the spectrum on SACS, and then interconnecting SACS to both the WACS and Monet subsea cables will create AmLight-SACS an express connection between Africa and the U.S. via Brazil. The impact from establishing AmLight-SACS has the potential to improve science flows to at least five science disciplines: Astronomy, Biological Sciences, Earth Sciences, Medicine, and Genomics. Furthermore, by adding a new South Atlantic path to key open Global Research and Educational (GRE) exchange points, the result aims to create a new network infrastructure that contributes to improving the global R&E fabric. Currently, most of the data is transferred via hard drives because there is no reliable network.

Biographies

Heidi MORGAN, Ph.D. is a Senior Computer Scientist at Information Science Institute (ISI) Internet and Networked Systems group at the University of Southern California (USC) Viterbi School of Engineering. Dr. Morgan moved to ISI from Florida International University where she was the Director and Co-Founder of the Center for Internet Augmented Research and Assessment (CIARA www.ciara.fiu.edu). CIARA fosters a domain-specific tailoring of Internet technologies to support faculty research, and in the process improve graduate education. CIARA assesses and measures FIU's effectiveness in the use of technology to augment the rate of discovery for domain researchers.

Julio E. IBARRA, Ph.D, is the Assistant VP for Technology Augmented Research at Florida International University (FIU). He is responsible for furthering the mission of the Center for Internet Augmented Research and Assessment (CIARA) - to contribute to the pace and the quality of research at FIU through the application of advanced Cyberinfrastructure. He is responsible for strategic planning and development of advanced research networking services, including the development and management of the AMPATH International Exchange Point for R&E Networks. He is the Principal Investigator of multiple NSF International Research Networks Connection awards, involving the design and implementation of high-throughput international network connections to enhance U.S. e-science initiatives in Latin America, and the Caribbean.

Jeronimo BEZERRA is the Chief Network Engineer for CIARA at Florida International University. He has been involved with academic networks for the last 12 years. He is responsible for the operation of the AMPATH International Exchange Point in Miami, and the design and operation of the international network connections linking the research and education communities of the U.S., Brazil, Latin America and the Caribbean. He holds an MSc in Mechatronics and BS in Computer Science by the Federal University of Bahia/Brazil.

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Michael Stanton, Ph.D., Network Scientist at RNP, the Brazilian NREN. Formerly, full professor of computer networks at the Fluminense Federal University (UFF) in Niterói, Rio de Janeiro state between 1994 and 2014. Having helped to kick-start the Brazilian Internet in the 1990s, through his participation in setting up and running RNP, he later returned to RNP in 2002 as director of R&D. In September, 2019, Michael was inducted into the Internet Society’s Internet Hall of Fame in recognition of his work and contributions to advancing the Internet in Latin America.

Aluizio Hazin has been working for RNP (Brazilian NREN) for the last 10 years and since 2014 he is an IP network specialist in Engineering team. He has strong knowledge of IP routing, MPLS, DDoS mitigation technics and optical networks. He also
b\een leading the development of the RNP's international connectivity since 2013. Before RNP, he worked for IT company for 2 years supporting the local academic community. He holds a BS in Telecommunication Engineering by the University of the State of Pernambuco (UPE - PE/Brazil) and MBA from Fundação Getulio Vargas (FGV - RJ/Brazil).

Len Lotz is Executive Officer at Tertiary Education and Research Network (TENET South Africa). Len started off as a Mainframe Support person in the days of punch cards and paper tape before the IP Networking, PC and UNIX entered. The IT world changed during his employment history causing him to get into Software and Networking. He spent 10 years at the University of Cape Town in the IT department. When TENET was formed, he acted as a consultant and eventually joined as a Technical Staff Manager at TENET.

Mr. Siju Mammen is the head of Network Engineering at the South African Research Network (SANReN) at the Council for Scientific and Industrial Research (CSIR) since October 2011. He has been responsible for the pilot implementation of the South African Identity Federation (SAFIRE) and for the planning and rolling out of network infrastructure for the South African NREN. He holds Bachelors and an Honours degree in Computer Engineering as well as Masters degree in Nuclear Engineering.

References:

Backer, D. C. 'The Precision Array to Probe the Epoch of Reionization'. *Bulletin of the American Astronomical Society*, 449.

Bank, R. D. J. (1990) 'Observatories Review and Review Committee for SA Astronomy An in-depth review of SAAO and HartRAO, the South African Radio Astronomy Observatory, was carried out by the Foundation for Research Development (FRD), their parent body, which also funds university research in scientific and en-gineering disciplines. The reviewers were Prof D. Lynden-Bell (Cambridge) and', *Monthly Notes of the Astronomical Society of Southern Africa,* 49, pp. 26.

Brown, T., Baliber, N., Bianco, F., Bowman, M., Burleson, B., Conway, P., Crellin, M., Depagne, É., De Vera, J. and Dilday, B. (2013) 'Las Cumbres Observatory global telescope network', *Publications of the Astronomical Society of the Pacific,* 125(931), pp. 1031.

Brunt, J. W. and Michener, W. K. (2009) 'The resource discovery initiative for field stations: Enhancing data management at North American biological field stations', *BioScience,* 59(6), pp. 482-487.

Chaplin, W., Elsworth, Y., Isaak, G., Lines, R., McLeod, C., Miller, B., New, R. and van der Raay, H. (1996) 'Observing the sun with the Birmingham Solar-Oscillations Network (BISON)', *The Observatory,* 116, pp. 32-33.

Davidson, D. B. 'MeerKAT and SKA phase 1'. *ISAPE2012*: IEEE, 1279-1282.

DeBoer, D. R., Parsons, A. R., Aguirre, J. E., Alexander, P., Ali, Z. S., Beardsley, A. P., Bernardi, G., Bowman, J. D., Bradley, R. F. and Carilli, C. L. (2017) 'Hydrogen epoch of reionization array (HERA)', *Publications of the Astronomical Society of the Pacific,* 129(974), pp. 045001.

Dirks, R. D., Nyblade, A., Graham, G., Webb, S. and Jones, M. 'AfricaArray: Aims, Achievements and Future Activities'. *11th SAGA Biennial Technical Meeting and Exhibition*.

Gonzalez, A., Leigh, J., Peisert, S., Tierney, B., Lee, A. and Schopf, J. M. (2016) 'NetSage: Open Privacy-Aware Network Measurement, Analysis, And Visualization Service'.

Hessman, F. V. 'MONET: a MOnitoring NEtwork of Telescopes'. *International Astronomical Union Colloquium*: Cambridge University Press, 13-21.

Ibarra, J., Clark, R. and Morgan, H. L. 2015. IRNC: RXP: AtlanticWave-Software Defined Exchange: A Distributed Intercontinental Experimental Software Defined Exchange (SDX). USA: National Science Foundation.

Ibarra, J., Morgan, H., Lopez, L. and Cox, C. 2016. IRNC: Backbone: Americas Africa Research and eduCation Lightpaths (AARCLight). USA, Brazil, Africa: National Science Foundation (NSF).

Ibarra, J., Morgan, H. L. and Cox, D. 2015. IRNC: Backbone: AmLight Express and Protect (ExP). Miami, FL: National Science Foundation (NSF).

Kozłowski, S., Sybilski, P., Konacki, M., Pawłaszek, R., Ratajczak, M., Hełminiak, K. and Litwicki, M. (2017) 'Project Solaris, a Global Network of Autonomous Observatories: Design, Commissioning, and First Science Results', *Publications of the Astronomical Society of the Pacific,* 129(980), pp. 105001.

Leake, E. (2018) *URISC@SC17 and the #LongestLastMile*. AARCLight.net: CIARA FIU. Available at: https://aarclight.net/ubuntunet-connect-2017-3-2/ (Accessed: January 2018).

Lister, T., Anderson, D. and West, R. 'The Status of SuperWASP-South'. *Transiting Extrapolar Planets Workshop*, 108.

McNulty, S. A., White, D., Hufty, M. and Foster, P. (2017) 'The Organization of Biological Field Stations at Fifty', *Bulletin of the Ecological Society of America,* 98(4), pp. 359-373.

Minayo, M. C. d. S., Machado, J. M. H., Matos, L. B. F. d., Oda, L. M., Vieira, V. M. and Monteiro, T. C. d. N. 1998. Fiocruz saudável: uma experiência institucional. SciELO Public

Health.
Nordling, L. (2017) 'How the genomics revolution could finally help Africa', *Nature News,* 544(7648), pp. 20.
Osafo, C., Raji, Y. R., Burke, D., Tayo, B. O., Tiffin, N., Moxey-Mims, M. M., Rasooly, R. S., Kimmel, P. L., Ojo, A. and Adu, D. (2015) 'Human Heredity and Health (H3) in Africa kidney disease research network: a focus on methods in sub-saharan Africa', *Clinical Journal of the American Society of Nephrology,* 10(12), pp. 2279-2287.
Pepper, J., Kuhn, R. B., Siverd, R., James, D. and Stassun, K. (2012) 'The KELT-south telescope', *Publications of the Astronomical Society of the Pacific,* 124(913), pp. 230.
Qiu, W. (2019) *Angola Cables Activates Direct Optical Connection on SACS and MONET*. SACS. Online: Submanine Networks. Available at: https://www.submarinenetworks.com/en/systems/brazil-africa/sacs/angola-cables-activates-direct-optical-connection-on-sacs-and-monet 2019).
Raveloson, A. (2017) 'Managing Data from Seismic Networks Workshop'. *AfricaArray: Network reports*, August 20-26, 2017. Online.
Rocken, C., Meertens, C., Stephens, B., Braun, J., VanHove, T., Perry, S., Ruud, O., McCallum, M. and Richardson, J. (1995) 'Unavco academic research infrastructure (ari) receiver and antenna test report', *University Corporation for Atmospheric Research/University NAVSTAR Consortium (internal document)*.
Rodrigues, T. 2018a. The first, fastest connectivity, lowest latency trans-Atlantic link between Africa and the Americas. *SACS goes live, making gigantic leap in global connectivity.* Luanda, Angola: Angola Cable.
Rodrigues, T. 2018b. Intercontinental submarine cable between the United States and Brazil comes online providing high volume, high speed commercial connectivity services. Chicago: Angola Cable.
Rojas, J. M. V., Bittencourt, J., Heimback, P., Bernard, S. and Ferrão, P., Center), A.I.R.C.A. (2017) *A Science and Technology Agenda for an integrative approach to the Atlantic: Integrating Space, Climate, Oceans and Data Sciences through North-South / South-North Cooperation.* Terceira, Azores: Portuguese Foundation for Science and Technology (FCT)
Smith, S. W. (1986) 'IRIS: A program for the next decade', *Eos, Transactions American Geophysical Union,* 67(16), pp. 213-219.
Stewart, C. A., Cockerill, T. M., Foster, I., Hancock, D., Merchant, N., Skidmore, E., Stanzione, D., Taylor, J., Tuecke, S. and Turner, G. 'Jetstream: a self-provisioned, scalable science and engineering cloud environment'. *Proceedings of the 2015 XSEDE Conference: Scientific Advancements Enabled by Enhanced Cyberinfrastructure*: ACM, 29.
Stobie, R., Meiring, J. G. and Buckley, D. A. 'Design of the Southern African Large Telescope (SALT)'. *Optical Design, Materials, Fabrication, and Maintenance*: International Society for Optics and Photonics, 355-362.
Tydecks, L., Bremerich, V., Jentschke, I., Likens, G. E. and Tockner, K. (2016) 'Biological field stations: a global infrastructure for research, education, and public engagement', *BioScience,* 66(2), pp. 164-171.
Walker, A. R. 'South African Astronomical Observatory'. *Instrumentation and Research Programmes for Small Telescopes: Proceedings of the 118th Symposium of the International Astronomical Union, Held in Christchurch, New Zealand, 2–6 December 1985*: Springer, 33.
Wayth, R. B., Tingay, S. J., Trott, C. M., Emrich, D., Johnston-Hollitt, M., McKinley, B., Gaensler, B. M., Beardsley, A. P., Booler, T. and Crosse, B. (2018) 'The Phase II Murchison Widefield Array: Design overview', *Publications of the Astronomical Society of Australia,* 35.
Wenzel, Z., Klensin, J. and Huter, S. (1996) 'Network Startup Resource Center (NSRC)'.
West Africa Cable System (WACS) technically goes live, benefits soon to follow (2012).

Broadband. Online: oAfrica. Available at: http://www.oafrica.com/broadband/west-africa-cable-system-wacs-technically-goes-live/ (Accessed: Dec 4 2019).

Appendix A
Medical Research and Genomics

Project Title	Multidisciplinary Research for Malaria Control and Prevention in West Africa
Institution	Lead Institution: University of Sciences, Tech & Tech of Bamako, Bamako; Principal Investigator: Seydou Doumbia, M.D., Ph.D.
Summary	The overall goal of this ICEMR is to understand the variable effectiveness of current malaria control interventions in different ecological settings of West Africa. This goal will be accomplished by performing field and laboratory studies of the epidemiology, entomology (transmission), immunology and pathogenesis of malaria to characterize and understand: 1) The heterogeneity of malaria infection, disease and transmission, 2) The effects of control strategies on malaria transmission and pathogenesis, 3) The major obstacles to improving malaria control and potentially eliminating malaria, including drug and insecticide resistance
Collaborators	Project Leads: Nafomon Sogoba, University of Sciences, Techniques, and Technology of Bamako Mahamadou Diakite, University of Sciences, Techniques, and Technology of Bamako Sekou Fantamad Traore, University of Sciences, Techniques, and Technology of Bamako Collaborating Institutions: Tulane University, New Orleans, LA University of Georgia, Athens, GA University of Miami, Miami, FLA London School of Hygiene and Tropical Medicine, London, UK University of Copenhagen, Denmark Wellcome Trust Sanger Institute, Hinxton Cambridge, UK Malaria Immunology Section, Laboratory of Malaria and Vector Research, NIAID
Project Title	Malaria Transmission and the Impact of Control Efforts in Southern and Central Africa
Institution	Lead Institution: Johns Hopkins Bloomberg School of Public Health, Baltimore; Principal Investigator: William Moss, M.D., M.P.H.
Summary	The overall goal of the Southern and Central Africa ICEMR is to study the barriers to malaria control and elimination in Southern and Central Africa. The ICEMR will examine factors contributing to sustained malaria infections in high, moderate and low transmission settings. This goal will be achieved through a combination of: 1) State-of-the-art research on malaria epidemiology, vector biology, and the genetics of the malaria parasite in three different epidemiological settings in southern and central Africa, 2) Collaborations with national malaria control programs to develop locally-adapted control strategies, 3) Training, career development, and capacity building at research institutions in Zambia, Zimbabwe and the Democratic Republic of the Congo.
Collaborators	Project Leads: William Moss, Johns Hopkins Bloomberg School of Public Health Douglas Norris, Johns Hopkins Bloomberg School of Public Health Jennifer Stevenson, Johns Hopkins Bloomberg School of Public Health Collaborating Institutions: Macha Research Trust, Macha, Zambia Biomedical Research and Training Institute, Harare, Zimbabwe Tropical Diseases Research Centre, Ndola, Zambia University of the Witwatersrand, Johannesburg, South Africa National Institutes of Health Research, Harare, Zimbabwe Université Protestante au Congo, Kinshasa, Democratic Republic of Congo University of North Carolina-Chapel Hill, Chapel Hill, North Carolina University of Massachusetts Medical School, Boston, Massachusetts

Project Title	Program for Resistance, Immunology, Surveillance & Modeling of Malaria in Uganda (PRISM)
Institution	Lead Institution: University of California, San Francisco; Principal Investigator: Grant Dorsey, M.D.
Summary	This program called "PRISM" is based in Uganda and represents the East African region for the International Centers of Excellence for Malaria Research network. Uganda is emblematic of the challenges faced by high burden countries, where routine surveillance systems are inadequate to assess trends in the burden of malaria or to monitor the impact of control interventions. Through PRISM researchers have implemented a comprehensive malaria surveillance program including enhanced health facility-based surveillance and detailed longitudinal studies with differing transmission intensities. Complementary laboratory-based studies include surveillance for markers of antimalarial drug and insecticide resistance and serologic measures of malaria exposure.
Collaborators	Project Leads: Epidemiology: Moses R. Kamya, Makerere University and Infectious Diseases Research Collaboration (IDRC), Uganda Resistance: Samuel Nsobya, Makerere University and IDRC, Uganda Transmission: Sarah Staedke, London School of Hygiene and Tropical Medicine, U.K. Collaborating Institutions: Infectious Diseases Research Collaboration (IDRC), Kampala, Uganda Makerere University College of Health Sciences, Kampala, Uganda Liverpool School of Tropical Medicine, Liverpool, UK London School of Hygiene and Tropical Medicine, London, UK Radboud Institute for Health Sciences, Netherlands Stanford University, Stanford, CA Durham University, Durham, UK Institute for Health Metrics and Evaluation, Seattle, WA
Project Title	The Intransigence of Malaria in Malawi: Understanding Hidden Reservoirs, Successful Vectors and Prevention Failures
Institution	Lead Institution: Michigan State University, East Lansing; Co-Principal Investigators: Terrie Taylor, D.O. and Don Mathanga, M.D., M.P.H.
Summary	The primary objectives of research supported by the Malawi ICEMR are to identify, understand, and evaluate interventions that target the determinants of malaria disease. The Center aims to identify reasons why malaria in Malawi has remained resistant to usual control measures. Researchers will accomplish these objectives by systematically surveying populations of vectors, hosts, and parasites using newly developed molecular and genomic tools in conjunction with well-established epidemiologic approaches.
Collaborators	Project Leads: Miriam Laufer, Division of Malaria Research, Institute of Global Health, University of Maryland School of Medicine Don Mathanga, Malaria Alert Centre, University of Malawi College of Medicine Karl Seydel, College of Osteopathic Medicine, Michigan State University Collaborating Institutions: University of Malawi College of Medicine, Blantyre, Malawi University of Maryland School of Medicine, Baltimore MD University of Michigan, Ann Arbor MI Malawi-Liverpool-Wellcome Trust Clinical Research Programme, Blantyre, Malawi
Project Title	Environmental Modifications in Sub-Saharan Africa: Changing Epidemiology, Transmission and Pathogenesis of Plasmodium falciparum and P. vivax Malaria
Institution	Lead Institution: University of California, Irvine; Principal Investigator: Guiyun Yan, Ph.D.

Summary	The overarching goal of this ICEMR project is to assess the impact of human-induced environmental modifications such as dam construction, irrigation and shifting agricultural practices on the epidemiology, transmission, pathogenesis and immunology of Plasmodium falciparum and P. vivax malaria in highly populated Kenya and Ethiopia where major investments in water resource development projects are taking place.
Collaborators	Project Leads: Ming-Chieh Lee, University of California, Irvine Guiyun Yan, University of California, Irvine James Kazura, Case Western Reserve University, Cleveland Collaborating Institutions: Addis Ababa University, Addis Ababa, Ethiopia Burnet Institute, Melbourne, Australia Case Western Reserve University, Cleveland Jimma University, Jimma, Ethiopia Kenya Medical Research Institute, Kismu, Kenya

NIH HIV/AIDS clinical trial projects

Project Title	NIH HIV/AIDS Clinical Trials Networks
Institution	AIDS Clinical Trials Group (ACTG) HIV Prevention Trials Network (HPTN) HIV Vaccine Trials Network (HVTN) International Maternal Pediatric Adolescent AIDS Clinical Trials group (IMPAACT) Microbicide Trials Network (MTN)
Summary	In 2006 these clinical trials networks were restructured to better address emerging domestic and international challenges to developing improved HIV treatment and prevention strategies by creating a more integrated, collaborative and flexible research structure. The HIV/AIDS clinical trials Networks funded by the Division of AIDS (DAIDS) of the U.S. National Institutes of Health (NIH)
Collaborators	U.S. Military HIV Research Program (USMHRP) Centers for Disease Control and Prevention (CDC) Comprehensive International Program of Research on AIDS (CIPRA) Global Campaign for Microbicides (GCM) The Dale and Betty Bumpers Vaccine Research Center (VRC) Center for HIV/AIDS Vaccine Immunology (CHAVI) International AIDS Vaccine Alliance (IAVI) Collaboration for AIDS Vaccine Discovery (CAVD) Partnership for AIDS Vaccine Evaluation (PAVE)