University Corporation for Atmospheric Research (UCAR) – UCAR Community Programs (UCP)

COMET® – International Capacity Development Program (ICDP) Strategic Plan

2022 – 2032 Strategic Plan

01 October 2022

Table of Contents

FORWARD

In this strategic plan, the COMET International Capacity Development Program (ICDP) outlines our strategies and goals for the next ten years. Our desire is to become a recognized worldwide leader in international capacity development. Since 2014, ICDP has provided innovative technology solutions and conducted training for hydrometeorological institutions in the world's least-developed countries. We aim to expand our own capabilities to further boost the capacity of our partners with the goal of supporting the development of self-sufficient institutions in our partner nations that are able to safeguard their communities from high impact weather events and from the impacts of climate change, especially since some less-developed countries are also the most vulnerable.

The plan focuses on global leadership activities in five major areas of capacity development: low-cost environmental sensor development and implementation, numerical weather prediction (NWP) cloud computing applications, impact-based forecasting and warning services, implementation of innovative research and technology into societal applications, and competency-based educational resource development and training solutions. To satisfy these objectives, we have developed a series of short, medium, and long-term goals. We plan to implement our goals by developing sustainable and innovative instrumentation, leveraging partnerships with the international community and University Corporation for Atmospheric Science/National Center for Atmospheric Research (UCAR/NCAR) programs, and building a diverse, highly skilled staff. Our goals and objectives were developed to align with and complement those of UCAR, NCAR, and the World Meteorological Organization (WMO).

An essential part of our strategic plan is tracking and assessing accomplishments. In order to ensure we are meeting our strategic objectives, we have developed clear and concise metrics to measure our success. These metrics will be assessed at regular intervals and updated as needed.

ICDP 2022 - 2032 Strategic Plan

1. Introduction

Since its inception in 2014, COMET's® International Capacity Development Program (ICDP) has successfully built partnerships with national and international partners to enhance capacity in weather forecasting, environmental monitoring, impact-based forecast and warning services, competency based training, and communication of hydrometeorological information and early warning. Our association with the University Corporation for Atmospheric Research (UCAR) National Center for Atmospheric Research (NCAR) and UCAR Community Programs (UCP) allows us to leverage the breadth of unique expertise in research and education throughout the organization.

ICDP was established in 2009 (initially called RANET: RAdio and InterNET for the Communication of Hydro-Meteorological and Climate Related Information) to support the development and deployment of communication systems (i.e. Chatty Beetle) to provide emergency communications to communities in remote regions of environmental hazards. More recently, ICDP's top initiative has been developing and deploying the 3D-Printed Automated Weather Station (3D-PAWS) to expand weather observation networks in data-sparse environments. A 3D-PAWS system can be manufactured in about a week at a cost of only $300-500, using locally sourced materials, microsensor technology, low-cost single board computers, and a 3D printer. As of 2022, systems have been deployed in Austria, Barbados, Canada, Curacao, Dominican Republic, France, Germany, Kenya, Senegal, Trinidad and Tobago, Turkey, Uganda, United States, and Zambia,.

The ICDP has also worked to build capacity by developing forecaster competency training for our international partners. We have worked with our COMET education experts to deliver workshops and courses in nations such as Myannmar, Sri Lanka, La Reunion, and other countries around the world. ICDP is also partnering with NCAR to develop a cloud computing framework to meet least-developed nations' need for high-resolution weather forecasting modeling products. For more information about ICDP's current capabilities and ongoing projects, please refer to the supplemental information at the end of this document.

In the coming years, we intend to continue our global leadership in capacity-building and expand our technology and training to meet the ever-growing need for accurate and timely hydrometeorological information to reduce societal risk from environmental hazards.

1.1 Our Mission:
Our mission is to provide innovative, sustainable technology and comprehensive educational training to hydrometeorological institutions in least-developed regions of the world. We strive to build capacity with the ultimate goal of creating **self-sufficient** institutions able to utilize actionable meteorological and hydrological information to protect lives and mitigate the social and economic impacts of natural disasters.

1.2 Our Values:
Our cultural belief is that every society on Earth should have **access** to technology, education, and information to safeguard against meteorological and hydrological hazards. We strive to make the latest innovative technology and training resources available to everyone, especially the least-developed societies that have limited resources.

1.3 Our Vision:
Our vision is for ICDP to be recognized as a **global leader** in Earth Sciences capacity development; implementing innovative technology implementation and providing educational solutions to foster equity and to empower hydrometeorological institutions around the world to support the protection of people and their livelihoods from weather and climate related risks.

To advance our mission, values, and vision, ICDP will focus on its strategic objectives of continued global leadership in:

a. Low-cost environmental sensor development and implementation
b. Numerical weather prediction (NWP) cloud computing applications
c. Impact-based forecasting and warning services
d. Implementation of innovative research and technology into societal applications
e. Competency-based educational resource development and training solutions

1.4 Alignment with UCAR and NCAR goals and priorities:
The ICDP's mission and vision are closely aligned with the mission and vision of our parent organizations, COMET, UCP, and UCAR. The ICDP is a branch of COMET, which itself is an entity of UCP under our parent organization, UCAR. UCAR is a nonprofit consortium of 120 North American colleges and universities focused on research and training in atmospheric and Earth sciences.

The ICDP mission specifically supports UCAR's 2019-2028 strategic plan to "enable the transition of Earth system science research to operations and applications, resulting in the support of lives and property protection (and) economic development" and "champion and extend Earth system science education and outreach." [1]

COMET is one of UCAR's primary programs for education and outreach, with its stated mission of "advancing geoscience workforce expertise worldwide through innovative, customized training solutions and capacity building tailored to community needs."[2] ICDP mainly focuses on the international aspect of COMET's outreach, particularly by building partnerships with less-developed countries (LDCs) and Small Island Developing States (SIDSs). By building our partners' capacity, we aim to help safeguard life, property and economic opportunities threatened by high impact weather events and climate change.

ICDP closely collaborates with the National Center for Atmospheric Research (NCAR), which is a federally funded research and development center (FFRDC) established by the National Science Foundation and managed by UCAR. NCAR is a "national and international leader in atmospheric and Earth system science and technology", with its mission to "foster the transfer of knowledge and technology for the betterment of life on earth".[3]

NCAR offers unmatched scientific expertise, particularly in research and technological innovation. Their particular goal of pursuing research to protect critical infrastructure, lives, and property from high impact weather conditions aligns with the ICDP mission and offers the opportunity for a symbiotic relationship. ICDP can assist NCAR's mission of knowledge and technology transfer by bringing actionable science solutions to developing nations. In turn, partnering with NCAR will enhance ICDP's ability to bring the best and newest technological innovations to our international partners.

1.5 Alignment with WMO Strategic Plan:

The World Meteorological Organization (WMO) is a key partner and guidepost for ICDP in our quest to develop capacity in less-developed nations. In their 2020-2023 Strategic Plan, the WMO notes a growing capacity gap in National Meteorological and Hydrological Services (NMHS) abilities to provide "weather, climate, water and related environmental services to meet nation,

[1] University Corporation for Atmospheric Research, *UCAR Strategic Plan 2019-2028*, 2019, Boulder, CO. https://www.ucar.edu/who-we-are/strategic-plan-2019-2028.

[2] University Corporation for Atmospheric Research, *COMET Strategic Plan 2021-2036 (draft)*, accessed August 3, 2022.

[3] National Center for Atmospheric Research, *2020-2024 NCAR Strategic Plan*, 2020, Boulder, CO. https://ncar.ucar.edu/sites/default/files/documents/related-links/2020-08/NCAR_StrategicPlan_2020-24_Final_081720.pdf.

regional, and global requirements” [4]. Often the NMHSs facing the largest gaps are those most vulnerable to natural hazards.

The ICDP strategic objectives specifically align with and can help achieve two of WMO’s long-term goals:
“Goal 2: Enhance Earth system observations and predictions: Strengthening the technical foundation for the future” and
“Goal 4: Close the capacity gap on weather, climate, hydrological and related environmental services.”

In alignment with Goal 2, our development of WMO-approved, low-cost environmental sensors will allow less-developed nations to expand their observing networks as part of the WMO Integrated Global Observing System (WIGOS). Additionally, our leadership in cloud computing technologies will allow less-developed countries access to high-resolution numerical weather prediction capabilities over their own regions.

Regarding Goal 4, WMO notes “a growing deficit in the capability and numbers of adequately educated and trained (NMHS) in many countries and territories”, especially given “rapid advances in scientific innovation and technological developments and means for public communication.” ICDP’s partnerships with developing countries allow us to understand their capability gaps and determine tailored solutions to meet their needs. Our innovative training methods, touching on a wide variety of topics including impact-based forecasting, can help NMHSs “develop and sustain core competencies and expertise”. Finally, our focus on transforming research to operations will allow us to deliver training on the newest innovations and technologies to our international partners.

[4] World Meteorological Organization, *WMO Strategic Plan 2020-2023*, 2019, WMO-No.1225, Geneva, Switzerland: WMO Publications. https://library.wmo.int/doc_num.php?explnum_id=9939.

3D-PAWS deployment at schools in Kenya to provide weather observation access to teachers and students.

2. Strategic Objectives

As noted by the WMO, NMHSs in many regions of the world lack the necessary resources, trained staff, and/or infrastructure to provide state-of-the-art environmental services for the betterment of society. A need exists for sustainable observation networks, NWP modeling and forecast system frameworks, effective communication strategies, and trained staff to comprehend hydrometeorological observations and forecast models to make informed, impact-based decisions and communicate that information to reduce risk to society. ICDP is focused on sustaining a leadership role in expanding capacity to global partners. To address those these needs, ICDP will focus in five major themes:

2.1 Leadership in low-cost environmental sensor development and implementation

ICDP has successfully established an ever-expanding network of 3D-Printed Automatic Weather Stations (3D-PAWS) in LDCs and SIDSs around the globe. We will continue our global leadership in providing innovative instrumentation solutions by improving the current sensor designs to improve on accuracy and reliability, and conducting training to help our partners move toward self-sufficiency. We will develop new sensor capabilities to address the needs for observation input to enhance multi-hazard early warning capabilities. Our sensors will provide high-quality, reliable data that will meet the fit-for-purpose applications of our partners at a reasonable cost. An important aspect of leading this effort is to provide capabilities that promote free and open dissemination of data using a variety of communications/data solutions.

2.2 Leadership in Numerical Weather Prediction (NWP) cloud computing applications

Many NMHS seek high resolution, regional NWP for short-term operational forecasting, but often they lack the resources and infrastructure (reliable power, high-speed networks, and adequate climate-controlled facilities) to maintain and operate a high-performance computing (HPC) system. With the advancement and accessibility, cloud computing facilities have become cost effective and reliable solutions that allow NMHSs to run a NWP system without maintaining their own HPC. ICDP will partner with NCAR and other NWP and cloud computing experts to develop sustainable solutions for our NMHS partners. As an additional component of this initiative, we will develop educational resources and provide training to make cloud-based NWP systems a long-term sustainable solution.

2.3 Leadership in impact-based forecast and warning services

As outlined in WMO's Guidelines on Multi-Hazard Impact-Based Forecast and Warning Services (IBFWS), "improving observing and forecasting systems are necessary but not sufficient" to reduce adverse impacts from hazardous weather and environmental events.[5] NMHSs must employ impact-based forecasting and warning systems to identify specific impacts and allow those at risk to take appropriate actions. ICDP will continue to design and implement end-to-end IBFWS frameworks to help partner NMHS become more resilient to high-impact weather events. We will continue to develop and deliver comprehensive IBF training through workshops, scenario-based training with community stakeholders, and other educational resources e.g. IBF training modules on the COMET MetEd website, found at: https://www.meted.ucar.edu/education_training/course/92). We will partner with other experts in IBF to continuously improve our processes and methodologies.

2.4 Leadership in implementing innovative research and technology into societal applications

In partnership with UCAR/NCAR Programs along with other public and private international organizations, ICDP has access to cutting-edge research and development that can be adapted for user-driven applications. These technological advances in hydrometeorological require thoughtful planning and sustainable implementation. ICDP will serve as the focal point between our LDC and SIDS NMHS partners and the hydrometeorological research and development community. We will evaluate emerging technologies and support the integration of applications that aid decision making systems (e.g., early warning systems and emergency communication systems). We will strive to understand the needs of individual NMHSs and tailor these technologies into applications to meet their needs.

---

[5] World Meteorological Organization, *WMO Guideline on Multi-hazard Impact-based Forecast and Warning Services*, 2015, WMO-No.1150, Geneva, Switzerland: WMO Publications. https://library.wmo.int/doc_num.php?explnum_id=7901.

2.5 Leadership in competency-based educational resource development and training solutions

In support of WMO's focus on building and sustaining core competencies, ICDP has ongoing partnerships with several LDCs that can be leveraged to develop and deliver training targeting specialized needs for individual locations or entire regions. On a local level, our training will empower NMHSs to provide top-notch environmental services through impact-based forecasting and help community stakeholders respond to hazardous events. Regional training may look at a suite of different forecasting or environmental challenges across larger geographic areas. We will utilize COMET's training expertise to explore innovative training solutions to expand our reach, including remote learning opportunities.

3. ICDP Goals

Our goals are designed to help us meet our strategic objectives and are broken out into short (one to two year), medium (three to five year), and long term (six to ten years). These goals will be reassessed as needed at regular intervals.

3.1 One to Two Year Goals

3.1.1. Continued Innovative Instrumentation Development, Evaluation, and Implementation - ICDP will continue to improve the 3D-PAWS engineering by developing multiple low-cost, power and communication efficient data-logger solutions and improved designs for fabrication and assembly. We will expand sensor capabilities to monitor additional environmental parameters such as lightning, stream flow, air quality, and soil conditions. ICDP aims to expand 3D-PAWS networks to other LDCs and SIDSs in Africa, the Caribbean, and Southeast Asia.

3.1.2. Demonstrate a Multi-Hazard Early Warning System (MHEWS) - A MHEWS integrates hazard monitoring observations, forecasting input, disaster risk assessments, communication tools, and preparedness plans that enable governments, communities, and individuals to take timely action to reduce disaster risk in advance of hazardous events. ICDP will conduct a demonstration study with a partner nation(s) to utilize a low-cost, integrated observation network consisting of automatic weather stations (3D-PAWS), stand-alone rain gauges, stream gauges, and storm surge/tide gauges to support an initial MHEWS design.

3.1.3. Demonstrate WRF in a Cloud Computing Environment - In order to meet NMHS's high-resolution regional numerical weather prediction (NWP) requirements, ICDP will develop and demonstrate operating, with a partner institution, a regional WRF system in a cloud computing environment. The modeling framework will have an easy-to-use web-based graphical user interface (GUI) and allow users to configure optimal model grid domains, model physics, user-specific forecast products, and display the forecast fields in an easy-to-interpret web-based display framework.

3.1.4. Expanding Training Capacity - ICDP plans to enhance training resources on how to fabricate, deploy, set up a data management system, and use observations from 3D-PAWS and other low-cost sensor systems. The resources will include, but are not limited to, short videos, online training modules, and how-to guides. Additionally, we plan to expand our training resources to other topics such as IBFWS, core meteorological and hydrological competencies, cloud NWP modeling, and other topics of interest to end-users. An additional goal is to translate and provide the resources in multiple WMO-recognized languages.

3.2 Three to Five Year Goals

3.2.1 Expand the implementation of innovative instrumentation globally and support the development of regional fabrication sites - ICDP will continue to support the implementation of sustainable fabrication facilities with in-country partners for the manufacturing/implementing 3D-PAWS observation networks and the development of data-driven applications. We will ensure we have a framework to provide consistent, repeatable instrumentation with supportable software systems. We will work towards establishing regional fabrication sites and when possible partner with WMO regional training centers (RTCs). Finally, we will establish a follow-up support program with our partners to ensure a successful and sustainable implementation of 3D-PAWS networks.

3.2.2 Enhance data analysis and evaluation solutions for our partners - Our goal is to empower our partners to transform the data from our instrumentation into actionable hydrometeorological information. To assist in this goal, ICDP will expand training resources (e.g., learning modules, software tools, instruction guides) to support data analysis, data management, and application development for end-users. We will build and support a 3D-PAWS open-source toolkit (e.g,. Python software tools). Further, we will support data quality studies with partners to build knowledge to independently evaluate their own observational datasets

3.2.3 Utilize low-cost observation networks to address climate change adaptation and other societal applications - Beyond providing weather and climate observational data, ICDP will demonstrate practical application of that data for the betterment of society, particularly to address the threats of climate change. We will continue our work with USAID and build new relationships with the Red Cross, agricultural non-governmental organization (NGOs), Agriculture University Program and partners that are focused on addressing climate change, adaptation, and resilience at a community level. With our partners, we will develop tools to analyze observations, climate projections, and other information that is tailored to the concerns of local communities.We will also partner with GLOBE, Sci-Ed and other educational partners to develop climate-related resources, especially for the youth (K-12 education). We will aim to foster science education among the next generation of scientists, engineers, and community leaders so they are prepared to address climate change and build resilience to climate change-associated risks.

3.2.4 Develop and Implement an Impact Based Forecasting Framework - ICDP will create an end-to-end certificate course on how to develop and implement an IBFWS, incorporating education, tools, and technology and building a framework through communication and engagement with local stakeholders including, but not limited to NMHSs, emergency managers, and other sector leaders (e.g., aviation, transportation, health services, etc). We will develop and provide IBFWS tools including templates, processes and procedures, links to resources (e.g., emergency communication solutions and protocols such as Common Alerting Protocol) so institutions can build sustainable solutions. We will partner with donor agencies (e.g., World Bank, USAID) and other organizations (e.g., WMO, UK Met Office) to expand IBFWS to LDCs and SIDSs worldwide.

3.3 Six to Ten Year Goals

3.3.1. Become an recognized international capacity development center around the world- As we satisfy our strategic objectives, we hope to become recognized as a leading international capacity development center for the world. We will be a key tier-2 observational instrument provider for the WIGOS system and a trusted provider of competency-based education, including IBFWS. Through expanded partnerships with related sectors and institutions, we will make available to our partners a range of solutions and end-to-end frameworks (storm surge monitoring, air quality, hydrological monitoring, multi-hazard early warning systems, climate extremes, agriculture, hydroelectric dam operations, etc.) to build capacity and empower NMHS worldwide.

3.3.2. Further integrate with societal applications in developing countries that need weather and climate data - In an continuing effort to transform our data for practical applications, ICDP will explore using data to assist commerce and utility-related entities in LDCs, including solar and wind power companies, the transportation industry, the sports industry, the shipping industry, wildfire mitigation, and smart city solutions (i.e. managing air quality). We will incorporate data science in the development of adaptable and practical applications for the end users.

3.3.3 Be able to respond agilely to new technologies and to meet demand for low-cost sensor technology and training - Technology is rapidly changing and in some cases becoming faster and less expensive, and more widely available. To be leaders in international capacity development, ICDP must be able to agilely integrate new technologies into applications to serve the societal needs of LDCs and SIDSs. To do so, we will design our training to be changeable, flexible, and scalable to incorporate the new technological solutions. We will continue to leverage and expand our partnerships, maintaining strong networking connections with UCAR/NCAR, international organizations, and our LDC partners. Finally, we will build our work force with the skill sets to respond and develop solutions to address future environmental challenges.

3.3.4 Explore eco-friendly and sustainable practices - As we expand our footprint around the world, ICDP will work to make our own practices more eco-friendly and sustainable. We will continue to improve low-cost power options for our instruments (e.g., batteries, solar panels, and other energy sources). We will investigate methods for faster, more efficient production of our instruments and investigate the cost-effectiveness of 3D-printers that minimize micro-plastic waste. We will further explore other innovative manufacturing solutions such as injection molded designs, non-plastic materials, and using local sourcing.

Charles Mwangi installing a 3D-PAWS station in Kenya.

4. Implementing Our Goals

4.1 Partnering with the international community to advance earth science knowledge to the next generation globally

In response to recent natural disasters and threats from climate change, WMO, USAID, and donor institutions like World Bank have prioritized providing sustainable technology and innovative training to least-developed NMHS. These organizations are willing to provide considerable funding to support the implementation of new technology and training. These opportunities are expected to grow as funding agencies move away from acquiring and providing expensive, unsustainable technology (e.g., expensive observation systems, large on-site HPC's, etc.) to a framework that provides more agile and sustainable technology and provides training to further enhance local capacity and knowledge. This new paradigm aligns well with ICDP's mission and vision.

As a non-profit organization, UCAR depends on external funding to support its mission. Current partnerships with WMO, USAID, the US NWS have allowed ICDP to develop an initial low-cost observation and communication framework, implement IBF and early warning systems, and create and deliver competency-based training. Building and exploring new partnerships and coalitions within the international community will give us the opportunity to diversify our funding so we can expand capacity development projects, develop and deliver additional technology, and provide training to a broader community of LDCs and SIDSs. Diversified funding will further allow ICDP to be more agile and responsive to new opportunities.

The best opportunities for funding historically have been agencies such as USAID, United Nations Development Program (UNDP), Department for International Development (DFID), etc. New opportunities are emerging with donor agencies (e.g., World Bank), foundations (e.g., Gates Foundation), public-private partnerships such as TomorrowNow.org, Development Monitors, and other non-profit organizations. A key partnership for the ICDP is WMO. WMO is connected to 193 member states and territories and has an understanding of the technology and knowledge gaps around the world. WMO partners with other agencies to provide support programs to fill those gaps. ICDP is poised to support those initiatives working with WMO experts and partners.
With the help and support of the international partners, ICDP can reach more communities, working together to enhance weather and climate capacity worldwide.

4.2 Developing and Delivering Sustainable, Innovative Instrumentation

In order to develop and deliver sustainable, cutting-edge technology, ICDP will design innovative instrumentation that is version controlled, well-documented, repeatable, and scalable to meet the needs of our partners. Our international partners should be able to have the ability to manufacture a variety of systems designs supported by ICDP. Our goal is to provide observational solutions that meet the requirements to be considered a part of the baseline (or tier 2) network of the WMO Integrated Global Observing System (WIGOS)[6].

Transmitting timely data from our instruments is a necessity to harness the value of their environmental data. As communications capabilities vary around the world, we will develop a range of options for network connectivity (e.g. cellular, wi-fi, satellite uplink, etc.) and tailor solutions to specifically meet our partners needs. These options will be able to operate interchangeably and smoothly integrate into the instrument hardware.

All of our technology and coding will be open-source and thoroughly documented so our users can access, understand our design methods, and adapt the technology to their applications. We will provide proper guidance on instrument siting and calibration to ensure instruments meet WMO standards and are able to provide the most accurate data possible. We will also provide detailed documentation and training on system maintenance in line with our mission to help our international partners achieve self-sufficiency.

We will improve data display functionality and document data evaluation, management, and quality control practices for our partners. We will make available and publish the results of our own data evaluation. Finally, we will ensure the data from our sensors are archived and made available for assimilation into NWP systems, warning systems, and other practical applications.

4.3 Partnering with UCAR/NCAR Programs to advance the implementation of new research and development

ICDP retains a strong relationship with partner programs at UCAR (e.g., UCP and NCAR), which allow us to capitalize on their cutting edge research and training capabilities. For example, NCAR has been a key developer of the Weather Research and Forecasting (WRF) model and has been actively building cloud computing capability (e.g., WRF-in-the-Cloud). We plan to leverage our partnerships with these developers to bring this technology to LDCs and SIDSs. Future partnerships are possible with funding agencies, NMHS, national research centers, universities, and other partners to implement this technology to reduce risk and build sustainability from high-impact weather events (e.g., tropical cyclones, heavy rainfall events, long-term drought, etc.).

ICDP works closely with the educational development group at COMET, which has over 30 years of experience as the leading experts on developing and implementing innovative training methods for national and international meteorological and hydrological programs. COMET has partnered

[6] World Meteorological Organization, *Vision for the WMO Integrated Global Observing System in 2040*, 2019, WMO-No.1243, Geneva, Switzerland: WMO Publications. https://library.wmo.int/doc_num.php?explnum_id=10278.

with ICDP to deliver training programs on forecasting, observations, synoptic, tropical meteorology, and other hydrometeorological topics for NMHS and other stakeholders. The training courses have been conducted in-person (residence course and in-country) and by remote delivery. We will continue to utilize COMET's expert educational designers and content developers to meet the training needs of our partners and stakeholders.

Another UCAR program closely associated with COMET is also closely aligned with two UCP/Educational Training Center programs, the Global Learning and Observations to Benefit the Environment (GLOBE) and the Center for Science Education (Sci-Ed). GLOBE is a hands-on environmental science and education program focusing on international primary and secondary schools, while Sci-Ed focuses on fostering science education within the United States.
ICDP has partnered and will continue to work with GLOBE to provide weather observational capabilities at GLOBE partner schools. GLOBE and Sci-Ed within the UCP/Educational Training Center (ETC) can help ICDP develop educational training resources for teachers and students to better utilize observations from low-cost sensors to learn more about weather and climate to better understand the impacts of climate change in their community.

4.4 Building the capability of our staff while fostering diversity and inclusivity

The current ICDP staff have a well-rounded expertise in atmospheric science observation, modeling, and software and mechanical engineering design and development. We have built strong connections with the global community (e.g., WMO and associated NMHSs) that provide additional opportunities for program development. Our connections with the COMET training program provide access to leading experts on innovative training methods.

The ICDP program is currently understaffed to meet the growing needs for international capacity development. This limits our ability to implement new projects and enhance current technology and training methods. As a result, ICDP is not as agile as we would like to be to respond to new requests for capacity development projects.

In order to improve our ability to deliver capacity-building training and technology to meet demands, we will target a diverse and inclusive workforce that add a variety of new skill sets to the ICDP team. A technical writer would allow us to expand the documentation of our processes and maintenance of our code. This enhanced documentation would help us meet our mission of creating sustainable technologies and helping our partners achieve self-sufficiency. A data scientist would help us expand our data analysis capabilities and develop strategies to help our partners maximize their data. A marketing, outreach, and communications specialist could focus on networking and helping us expand our global reach. We also aim to bring in additional researchers in identified growth areas, e.g.. climate science or agriculture. Finally, we will develop a succession plan to replace our current team members who plan to retire.

ICDP recognizes the advantages of fostering a diverse and inclusive culture. We will seek to hire individuals who can bring varying skills, experiences, and perspectives to enrich our team. When developing position descriptions for future candidates, we will target the widest possible audience by authorizing remote work and carefully delineating between required versus desired job skills. We aim to partner with UCAR DEI programs such as Significant Opportunities in Atmospheric Research and Science (SOARS) and maintain an active representative on the COMET DEI team. We will participate in networking opportunities aimed at early career scientists and underrepresented groups through American Meteorological Society (AMS) and American Geophysical Union (AGU). Finally, we will continue to build a culture of honest communication and teamwork that embraces an open exchange of ideas.

Storm surge gauge installation in Dominican Republic.

5. Measuring Success

An important part of any plan is having achievable goals and objectives. We will use the following matrices to assess our progress toward achieving each strategic objective. The matrices will be evaluated on a yearly basis and measures of success may be added as necessary. Ultimately, we hope to be recognized by the WMO as an International Capacity Development Center, which would encompass all five of our strategic objectives.

5.1 Leadership in low-cost environmental sensor development and implementation

We can measure our success in innovative implementation by evaluating our framework for delivering new sensors and training and asking if it is repeatable, consistent, and sustainable. We can also quantify when and where our new instruments are deployed. Since we are aiming to build our partner's self-sufficiency, we must also measure our partners' ability to maintain and keep their own equipment operational, fabricate new equipment, and use and evaluate their own data.

Measure	Target	Actual
Have we implemented a consistent, repeatable framework for our instrumentation that is easy to deploy?	Yes	
In how many new locations have we implemented 3D-PAWS per year?	50	
How many new sensors are operational?	60%	
What is the average lag time between requests for support and delivery of training and materials? Are we improving?	6 months	
Have the countries that received 3D PAWS training been able to manufacture and implement additional units themselves?	Yes	
Are our instruments able to operate over a long period of time?	Yes	
Have we developed new ways to display instrumentation data?	Yes	
Are we publishing our own analysis of 3D-PAWS data?	Yes	
Are our partners able to evaluate their own data and are they accessing the data currently available? (Website hits)	Yes	
Are we developing new instrumentation that is faster, more cost-effective and more eco friendly?	Yes	

5.2 Leadership in Numerical Weather Prediction (NWP) cloud computing applications

Once we have demonstrated a WRF-in-the-Cloud framework and tested its utility in one country, we want to expand this capability to other LDCs that have gaps in high-resolution modeling. We plan to measure success by the number of countries in which we have implemented cloud-based high-resolution modeling and if they are able to receive and use timely and reliable model data.

Measure	Target	Actual
Have we demonstrated WRF in the Cloud in a test region?	Yes	
Does WRF in the Cloud provide timely and reliable data?	Yes	
In how many countries or regions have we implemented WRF-in-the-Cloud per year?	2	
Are our partner nations able to maintain their cloud computing systems once implemented?	Yes	

5.3 Leadership in Impact-based forecasting and warning services

We will assess our development of the IBF framework by counting both the number of training workshops we have delivered and the completion of online training modules. We will also assess MHEWS implementation partner countries. We will conduct follow-up communications to assess how our partners are incorporating IBF and MHEWS into their forecast operations.

Measure	Target	Actual
Have we implemented the MHEWS and is it operational?	Yes	
How many countries have implemented MHEWS?	3 by 2025	
Have we developed and implemented our IBF framework?	Yes	
How many countries are using our IBF framework?	5 by 2026	
Have we developed the desired IBF training modules?	Yes	
How many countries have received IBF training?	10 by 2028	

5.4 Leadership in implementation of innovative research and technology into societal applications

At ICDP, we want to move beyond just providing environmental data and toward providing data for practical applications. We can measure our success by assessing new and existing partnerships and funding opportunities that assist us in transitioning research to operations. We also must assess if ICDP is able to respond agily to new technologies to meet the demand for low-cost sensor technology and training.

Measure	Target	Actual
Have we built new partnerships with agencies working on weather, climate adaptation, and other applications?	Yes	
Have we moved beyond just providing data, but are providing data for a purpose?	Yes	
Have we developed new sources of funding?	Yes	
Are we able to respond agility to new technologies to meet demand for low-cost sensor implementation and training?	Yes	
Have we added desired staff and replaced departing staff with the skills we need?	Yes	
Have we maintained partnerships with UCAR/NCAR and international organizations?	Yes	

5.5 Leadership in Competency-based educational resource development and training solutions

We will measure our training reach by quantifying the number of new training videos and modules we have made available to our partners, especially as technology evolves. We will measure the number of hands-on and online training sessions we provide and follow up with our partners to assess the efficacy of our training.

Measure	Target	Actual
How many training workshops have we provided?	3/year	
Have we made our 3D-PAWS training videos and modules available? (Number of views?)	Yes, 500	
Are we developing new training modules as technology evolves?	Yes	
Are we building self-sufficient partners who can train their own teams and stakeholders?	Yes	

3D-PAWS installation at the University of Nevada-Reno.

Anne Heggli installing a 3D-PAWS stream gauge in California.

Supplemental Information

3D PAWS background:
(from: https://docs.google.com/document/d/1PbxCOB15sTTfNSB7fHhIRnGSlZmCA_47/edit#)

Many surface weather stations across the globe suffer from incorrect placement, poor maintenance and limited communications for real-time monitoring. To expand observation networks in sparsely observed regions, the low-cost, high-quality 3D-PAWS (3D-Printed Automatic Weather Station) was developed through funding from the US NWS International Activities Office (IAO), with support from the USAID Office of US Bureau of Humanitarian Assistance (BHA). A 3D-PAWS surface weather station can be manufactured in about a week, at a cost of only $300-500, using locally sourced materials, microsensor technology, low-cost single board computers, and a 3D printer. 3D-PAWS sensors currently measure pressure, temperature, relative humidity, wind speed, wind direction, precipitation, and visible/infrared/UV light. The system uses single-board computers (SBCs) (e.g. Raspberry Pis, Arduino, and other low-power microcontrollers) for data acquisition, data processing, and communications. New sensors are being developed to monitor water level (stream gauging), soil moisture and temperature, and air quality.

3D-PAWS sensors were evaluated at the UCAR Marshall Research Facility in Boulder, Colorado and the NOAA Testbed facility in Sterling, Virginia. The Boulder site provides sampling conditions in a high-altitude semi-arid environment with subfreezing temperatures and frozen precipitation. The NOAA site provides sampling for a more temperate and humid climate near sea-level. COMET is currently collaborating with World Meteorological Organization (WMO) and the Turkish State Meteorological Service (TSMS) to deploy a 3D-PAWS network with the focus on testing and evaluation.

3D-PAWS real-time data are available on the CHORDS project data server. CHORDS (Cloud-Hosted Real-time Data Services for Geosciences) is a US National Science Foundation (NSF) EarthCube initiative to provide a platform for sharing geosciences datasets. It is supported and managed by the UCAR/National Center for Atmospheric Research (NCAR) Earth Observing Laboratory (EOL).

3D-PAWS systems have been deployed in the United States, Canada, Kenya, Uganda, Zambia, Barbados, Curacao, Trinidad, Senegal, Germany, and Austria, with new systems being installed in other locations in the Caribbean, Central America, Africa, and Asia. The primary focus in the United States is on testing and evaluation. COMET has partnered with schools, radio stations, NGOs, non-profit organizations, national meteorological and hydrological services, and international research institutes to expand 3D-PAWS networks around the globe.

The 3D-PAWS systems can be used for a variety of applications. Observations from the 3D-PAWS network can be assimilated into regional numerical weather prediction systems such as the Weather Research and Forecast (WRF: http://www.wrf-model.org) model to improve mesoscale weather forecasts. Real-time monitoring of precipitation in ungauged or minimally gauged river basins can provide input to flash flood guidance and early warning decision support systems to support delivery of flood alerts. 3D-PAWS can support water resource management tools to improve reservoir operation for fresh water supplies and the generation of hydroelectric power. Other applications include operation of irrigation systems and agricultural crop monitoring as well as monitoring conditions leading to outbreaks of diseases such as meningitis and malaria.

Numerical Modeling Support

COMET works with WRF model developers and trainers at UCAR/NCAR to help deploy this mesoscale model into NMHSs around the world. Most recently, COMET helped facilitate the deployment of WRF into the Thai Meteorological Department. In many developing nations, mesoscale models provide important, local guidance for weather forecasters and can thus have an important impact on improving forecast services to their stakeholders.

Data Display and Integration

IDCP works alongside staff from UCAR's Unidata program, to implement data display systems worldwide including the Integrated Data Viewer (IDV) and the Advanced Weather Interactive Processing System (AWIPS). Many developing countries are challenged by a variety of separate operational systems, each of which have their own display system. Both IDV and AWIPS can integrate these data streams to provide all data on one system to allow for better evaluation in forecasting operations. Currently, the Kingdom of Saudi Arabia is working to implement AWIPS in their meteorological service.

RANET/Chatty Beetle/EMWIN/LRIT/HRIT

The ICDP evolved and expanded from the International Extension and Public Alert Systems (IEPAS) program in 2014. IEPAS focused primarily on projects to improve rural and remote communication of meteorological information. The IEPAS program grew out of the original program called RANET (Radio and Internet for the Communication of Hydro-Meteorological and Climate Related Information). IEPAS was established to address a wider range of communication issues than that undertaken by RANET, including development of communication tools, training of stakeholders, and development of observation solutions and management of pilot projects. The program continues to work in parts of Africa, Asia, Pacific region, Central America, and the Caribbean. ICDP continues to support RANET/IEPAS initiatives such as Chatty Beetle, EMWIN, LRIT and HRIT.

ICDP has managed the Chatty Beetle program since 2009. The Chatty Beetle provides a critical emergency communication interface that is designed to operate in remote locations and under difficult environmental conditions. It sends and receives short text messages over the Short Burst

Data (SBD) service of the Iridium constellation of telecommunication satellites, which provides true global coverage that few other systems can match. Chatty Beetles are invaluable before, during and after hazardous events by fulfilling the following roles:

- As a "heads-up" device, the Chatty Beetle can provide early warning of impending hazards to even the most isolated communities;
- Provide vital links for emergency management and community leaders during and after a hazardous event;
- Used for rapid evacuation or during an operation where mobility is essential, such as in a search and rescue mission;
- Provide useful synoptic weather observations from remote islands, providing valuable data to the global forecast models that produce advanced warning of approaching severe weather.

Without Chatty Beetles, many residents of the island states of the Pacific would be without an effective system of emergency communications, leaving them vulnerable to approaching tropical cyclones or tsunamis.

The Emergency Managers Weather Information Network (EMWIN) is a U.S. National Oceanic and Atmospheric Administration (NOAA) National Weather Service- (NWS) operated system that provides a highly reliable stream of basic warning messages, low resolution graphics, and a variety of text products (e.g. METARS) suitable for emergency managers. Low Rate Information Transmission (LRIT) is a standard adopted by the WMO for the rebroadcasting of meteorological satellite imagery. EMWIN and LRIT systems deployed through the RANET program have been providing weather data and emergency warnings to remote locations in the Pacific region for over 10 years. Although primarily intended as a backup system, EMWIN and LRIT have often been a primary source of meteorological data for countries without enough infrastructure to support other systems.

With the introduction of the next generation of GOES satellites, the two broadcasts have been combined into a single HRIT/EMWIN stream employing High Rate Information Transmission (HRIT), the latest standard adopted by the WMO for rebroadcast of meteorological satellite imagery.

In 2019, COMET completed the first of a two-pronged upgrade of all the RANET equipment in the Pacific to make them HRIT/EMWIN compatible. The second push has involved the development and deployment of a smaller, low-cost system to Emergency Management Offices based on an inexpensive software defined radio (SDR) receiver and software developed by the Aerospace Corporation under a contract with NOAA. The required system components were tested and vetted during fall 2019 - spring 2020. All systems have been packaged, documented and shipped to the University of Hawaii for deployment in the Pacific Island region. In addition to providing the new equipment, COMET has also conducted regional training workshops in Hawaii and Fiji in conjunction with the University of Hawaii.

3D-PAWS training and installation in Trinidad and Tobago

Acronym List

3D-PAWS - 3D-Printed Automatic Weather Stations
DEI - Diversity, Equity, and Inclusion
DFID - Department for International Development
FFRDC - Federally Funded Research and Development Center
GLOBE - Global Learning and Observations to Benefit the Environment
HPC - High Performance Computing
IBF - Impact Based Forecasting
IBFWS - Impact Based Forecasting and Warning Service
ICDP - International Capacity Development Program
LDC - Least Developed Countries
MHEWS - Multi-Hazard Early Warning System
NCAR - National Center for Atmospheric Research
NMHS - National Meteorological and Hydrological Services
NWP - Numerical Weather Prediction
NWS - National Weather Service
RTC - Regional Training Center
SIDS - Small Island Developing States
UCAR - University Corporation for Atmospheric Research
UCP - UCAR Community Programs
UCP ETC - UCP Education and Training Center
UNDP - Nations Development Program
USAID - United States Agency of International Development
WIGOS - WMO Integrated Global Observing System
WMO - World Meteorological Organization
WRF - Weather Research and Forecasting