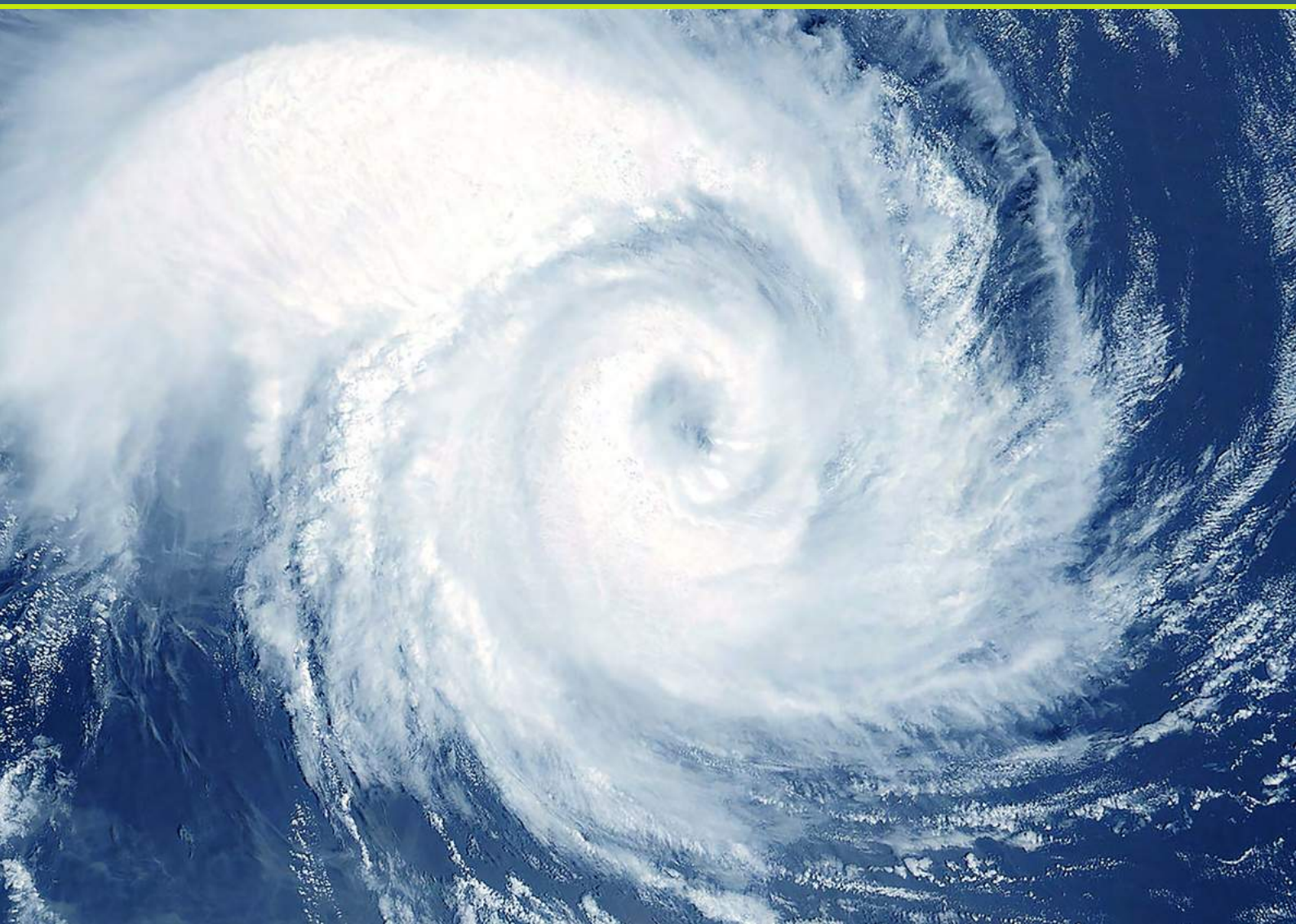
Met Office

The Weather and Climate Science for Service Partnership Programme

Programme impact and achievements

2023

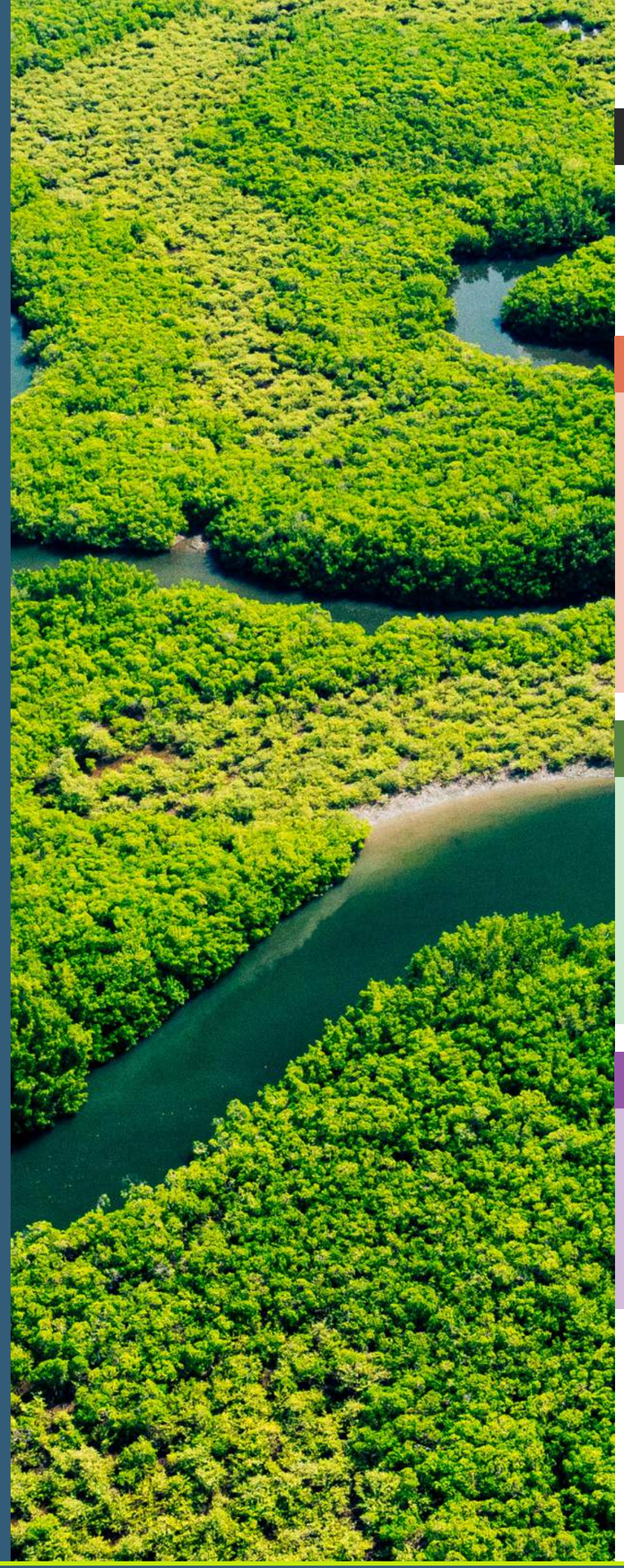


Met Office

What is the Weather and Climate Science for Service Partnership (WCSSP) programme?

International collaboration is vital to addressing the global challenges presented by extreme weather and climate change. Since 2014, the WCSSP programme has been developing a global network of partnerships that harness weather and climate scientific expertise. Through the programme, the Met Office and other UK institutions collaborate with partners in Brazil, China, India, Indonesia, Malaysia, the Philippines, South Africa and Vietnam.

The programme is supported by the UK Government and aims to strengthen the weather and climate resilience of communities around the world and help safeguard lives and livelihoods from the impacts of extreme weather and climate change.



“I’m proud to have seen WCSSP grow into a global network of collaborative research partnerships. The programme has already delivered numerous weather and climate services that are helping protect lives and livelihoods around the world and I’m looking forward to its continuation in the future to further strengthen global resilience to extreme weather and climate change.”

Professor Stephen Belcher, Met Office Chief Scientist

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Programme impact

650

peer-reviewed **research publications** have been published in international journals. Over half of these were co-authored between UK and partner countries.

1 million +

online views of research publications and over **350,000** downloads.

350 +

people trained in various weather and climate topics giving people the opportunity to learn new skills.

14,000 +

academic citations of research publications showing the significant contribution the programme is making to advancing the global knowledge base.

1000 +

international **news articles** or **blogs** have featured WCSSP research and over 7000 tweets and retweets.

100 +

research exchange visits between partner organisations have enhanced scientific collaboration and expanded researchers' scientific networks.

150 +

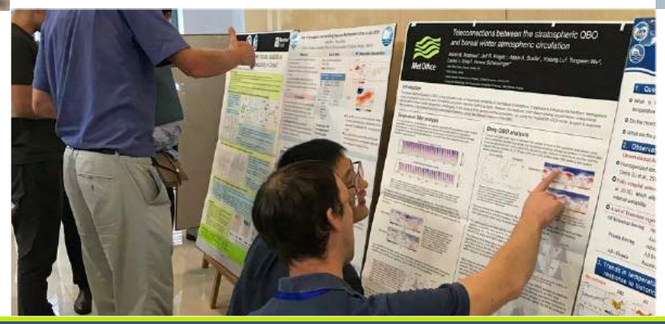
policy documents from **17 different countries** cite WCSSP research, highlighting the research is influencing the development of policies, strategies and standards around the world.

60

institutes have cited WCSSP research including Governments, Think Tanks and intergovernmental organisations such as the Intergovernmental Panel on Climate Change and the United Nations.

30

new or improved **weather and climate service products** developed.



300

workshops and **conferences** have had WCSSP researchers feature their research.

Met Office

WCSSP project partners and overviews

Climate Science for Service Partnership (CSSP) Brazil

Launched in 2016, the CSSP Brazil project is a collaborative climate science initiative between the Met Office and other UK research institutes, Brazil's National Institute for Space Research (INPE), National Institute for Amazon Research (INPA) and the National Centre for Monitoring and Early Warning of Natural Disasters (CEMADEN).

Climate Science for Service Partnership (CSSP) China

Launched in 2014, the CSSP China project has developed strong scientific partnerships between institutes in China and the UK, including the Met Office, the China Meteorological Administration, and the Institute of Atmospheric Physics at the Chinese Academy of Sciences.

Weather and Climate Science for Service Partnership (WCSSP) India

Launched in 2018, the WCSSP India project is a collaborative initiative between the Met Office, UK academic partners and the Indian Ministry of Earth Sciences (MoES).

It builds on existing partnerships between the Met Office and MoES institutes including the National Centre for Medium Range Weather Forecasting and India Meteorological Department. It also includes other MoES institutes such as the Indian Institute of Tropical Meteorology, the Indian National Centre for Ocean Information Services, the National Centre for Coastal Research and the National Centre for Polar and Ocean Research.

Weather and Climate Science for Service Partnership (WCSSP) South Africa

Launched in 2015, the WCSSP South Africa project is a collaboration between the Met Office and UK research institutes and the South African Weather Service (SAWS), the Applied Centre for Climate and Earth System Science (ACCESS), The Council for Scientific and Industrial Research (CSIR), The Agricultural Research Council (ARC), and the Global Change Institute (GCI) at the University of Witswatersrand.

Weather and Climate Science for Service Partnership (WCSSP) Southeast Asia

Launched in 2016, WCSSP Southeast Asia is a regional project with collaborations between the Met Office and UK research institutes, the Philippines, Malaysia, Indonesia and Vietnam. Institutes involved in the project include:

- The Philippine Atmospheric, Geophysical and Astronomical Services Administration.
- Malaysian Industry-Government Group for High Technology (MIGHT) delivering through; the National Disaster Management Agency (NADMA); the Malaysian Meteorological Department (Met Malaysia); and the Department of Irrigation and Drainage (DID).
- Agency for Meteorology Climatology and Geophysics of The Republic of Indonesia.
- The Vietnam Meteorological and Hydrological Administration.

Find out more about the WCSSP projects on the Met Office website

Met Office

Overcoming challenges in tropical cyclone forecasting

Tropical cyclones are one of the most powerful and destructive natural hazards. Hundreds of millions of people are affected by tropical cyclones every year. Extreme winds from cyclones can damage property and intense rainfall can lead to flooding and landslides. Through international collaboration, the WCSSP programme is advancing our understanding of tropical cyclones and helping forecasters around the world provide more accurate warnings of cyclones.

CSSP China

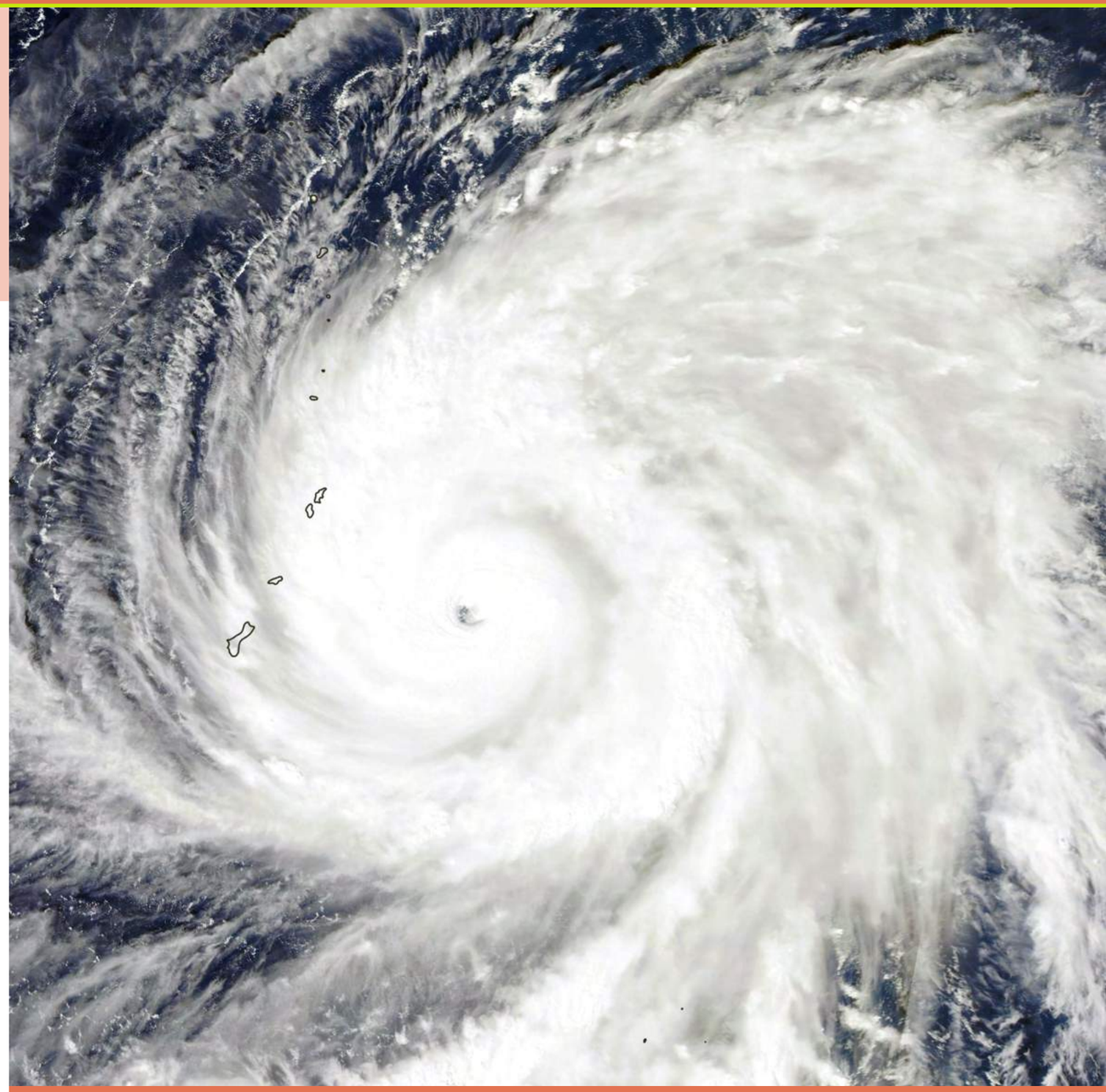
Increase in tropical cyclone risk to coastal regions

Also known as hurricanes in the North Atlantic and typhoons in the northwest Pacific, tropical cyclones have maximum wind speeds of at least 74 miles per hour and can be up to 1000 kilometres in diameter. Research by Imperial College London as part of the CSSP China project found that the activity of cyclones in coastal regions has changed recently. Analysing global data from 1982-2018 they found that tropical cyclones at their maximum intensity are moving 30 kilometres closer to coasts every decade. The study also found that the number of cyclones within 200 kilometres of land is increasing by an average of two more cyclones per decade.

Cyclones that are classified as major storms at landfall are of particular concern as they can cause significant damage to coastal regions. The team at Imperial College London found that the number of tropical cyclones that make landfall as major storms has nearly doubled from 1982 to 2020. The research is informing the private and public sectors to re-evaluate their risk to tropical cyclones to take account of the climate change that has already happened.

Creating a seasonal tropical cyclone forecast service in East Asia

The CSSP China project has developed a seasonal forecast of tropical cyclone landfall risk along the coast of Eastern China. The first trial forecast was released in 2019 and the Met Office has now issued the forecast in real time for four successive years. This trial climate service is issued to the China Meteorological Administration, who use the Met Office product to inform the development of the official China forecast of major meteorological hazards for the coming seasons.



Research by Imperial College London as part of the CSSP China project found the number of tropical cyclones that make landfall as major storms has nearly doubled from 1982 to 2020.

WCSSP Southeast Asia

Atmospheric waves and cyclone formation

Accurate and reliable forecasts of tropical cyclones are vital for protecting lives, livelihoods and infrastructure. However, there are many factors that affect the movement and intensity of tropical cyclones and predicting the generation of cyclones over five days ahead is a significant challenge.

Research by the University of Reading as part of the WCSSP Southeast Asia project has uncovered insights into the role of equatorial waves, which are atmospheric waves that are trapped near the equator, in the formation of cyclones. The researchers analysed over 3,400 tropical cyclones globally and found that westward moving equatorial waves signalled the formation of over 80% of the strongest tropical storms. This is due to these waves leading to favourable conditions for the formation and development of tropical cyclones. This finding could be used to identify the locations of future tropical cyclones and help the development of earlier warnings.

Overcoming operational challenges in cyclone forecasting

Seasonal forecasts provide information about the likely weather conditions several months ahead. These types of forecasts for tropical cyclones could significantly help decision makers and emergency management authorities improve preparedness ahead of the tropical cyclone season by providing insights into the number of cyclones that may occur in a region.

Through WCSSP Southeast Asia, researchers from institutes in the UK, the Philippines and Vietnam have identified a new approach to predict the number of cyclones that may occur in the tropical west Pacific up to four months ahead. One of the researchers, Xiangbo Feng from the National Centre for Atmospheric Science, commented, “This new approach is a good example of an outcome of research-focused and needs-driven collaborations. It was exclusively defined to tackle an operational forecast challenge of our partners in the Philippines and Vietnam. Existing models struggle to make accurate forecasts of tropical cyclones during the peak season from July to September over this region. This new method, based on preceding-season predictors, has a good skill, and provides a solution to our partners.”

As a collaborator on the project, Alvin Pura from the Philippine Atmospheric, Geophysical and Astronomical Services Administration commented “Our next step will be to conduct further trials of the forecasting model and determine how this can be implemented operationally. Predicting the number of tropical cyclones during peak season from July-September, several months in advance will be helpful to our cyclone seasonal forecasting capability”.

> *“In WCSSP Southeast Asia, we are undertaking fundamental research into the processes operating in tropical cyclones. We’re improving their representation in computer models to increase forecast accuracy, ensuring forecasters make optimal use of those models and improving how warnings are communicated to stakeholders and the public to save lives across the region.”*
>
> **Keith Williams, Head of Atmospheric Processes and Parametrizations, Met Office**

Developing solar radiation forecasts

Understanding how weather and climate impact renewable energy systems is vital for building resilience in a changing climate. Accurate predictions of weather conditions at site specific locations help to predict output from wind and solar energy systems, which helps to ensure the grid is balanced between demand and supply, reducing the risk of power outages. The WCSSP South Africa project has been investigating how site-specific solar radiation forecasts can be used to predict solar power in South Africa.

WCSSP South Africa

Solar energy in South Africa

South Africa is currently experiencing a mismatch between electricity demand and supply. This has resulted in frequent load shedding, which is the deliberate shutdown of electric power in parts of a power-distribution system to prevent the failure of the entire system when demand threatens to exceed supply.

The stress on the energy sector is expected to be further exacerbated by the impacts of climate change resulting in detrimental impacts on energy-intensive industry sectors that are crucial for the South African economy such as agriculture. Building a resilient energy network is therefore important from both an economic and environmental perspective, and reliable renewable energy production forms a crucial element of this network.

The South African Department of Energy has committed to achieving 40% renewable energy by 2030, with plans that a third of this supply will come from solar energy. South Africa is well placed to capitalise on solar energy, with an average of 2500 sunshine hours per year.

International collaboration to forecast solar power

The Met Office and South African Weather Service have been investigating how site-specific solar radiation forecasts can be used to predict solar power, by comparing site-specific solar radiation forecasts to observations at 12 sites across South Africa. It is hoped that these forecasts could enable energy system operators to optimally dispatch solar and other energy sources to balance the generation and demand. This will enable the electric grid to be more flexible and adapt to changing conditions as well as minimize disruptions.

We have developed and shown that forecasts for solar radiation in South Africa are accurate up to three days in advance. This information is relevant to support a growing renewable energy sector in South Africa.

Karen Walter, Managing Scientific Consultant, Met Office

Through collaboration between South Africa and the UK, we have made good progress on the development of solar power forecasting. We are hoping to move to wind power forecasting in the coming year or two.

Henerica Tazvinga, South African Weather Service

Identifying severe thunderstorms and lightning

Thunderstorms are associated with numerous hazards including heavy rainfall and lightning. In addition to these hazards, tiny ice crystals can form within the storm's rapidly growing clouds. These high-altitude crystals can be particularly dangerous to aircraft as they can stick to aircraft instruments. As part of the WCSSP India project, researchers have developed a tool that uses satellite imagery to identify where these ice crystals may occur to help warn people of the potential dangers.

WCSSP India

Monitoring ice crystals from space

High-altitude ice crystals can stick to aircraft instrumentation which can lead to potentially catastrophic consequences such as aircraft experiencing power loss. These ice crystals are so small that even in high concentrations they cannot be detected by aircraft radars. To overcome this challenge, researchers from the Met Office have developed a new tool which uses satellite images to identify locations that have a high probability of high-altitude ice crystals.

The tool combines images from five satellites to offer a global picture of where severe storms with a high probability of high-altitude ice crystals are forming. The tool can be used on any region and produces a new global picture every 30 minutes allowing users to see storms developing in near real-time. The tool is currently being trialled and it is hoped it could be used in cockpits by pilots in the future to provide an insight into where these potentially dangerous ice crystals are forming.

> *"Identifying where hazardous high-altitude ice crystals are likely to form is a global challenge. This is the first tool to offer a near real-time global picture of locations that have a high probability of high-altitude ice crystals"*

Rory Gray, Senior Scientist, Met Office

Read the full case study on the **Met Office website**

Improving the forecasting of lightning

Lightning is a severe natural hazard, which can damage infrastructure, impact transportation industries, and affect many people around the world. The Met Office is collaborating with the National Centre for Medium Range Weather Forecasting (NCMRWF) in India to improve the quality of lightning forecasts over India.

As the location of high-altitude ice crystals can indicate regions of intense storm activity where lightning strikes are likely to occur, the new tools being developed can also be used to help evaluate computer model forecasts of lightning. This will help to identify aspects of the model simulations that need improving in order to produce more accurate lightning forecasts, which would help save lives and protect livelihoods around the world.

Saji Mohandas, Model Development Group Lead at NCMRWF commented, "There is still limited understanding in the link between the evolution of ice crystals and soft hail with observed lightning flash counts. Additionally, evaluating the accuracy of atmospheric models for predicting lightning in different weather conditions also needs attention. The new tool under development will be beneficial in addressing some of these issues in conjunction with other observations."

Met Office

Jointly developing a seasonal rainfall forecast service

The Yangtze River Basin is home to more than 400 million people and is a key agricultural region in China. The region is prone to flooding on a semi-regular basis due to the influence of the East Asian Summer Monsoon. Researchers from the CSSP China project have jointly developed a seasonal forecasting service for summer rainfall in the Yangtze River Basin. The service is helping users in the region make early decisions to manage flooding in addition to supporting the production of hydroelectric power which is essential for the large cities of eastern China.

CSSP China

Seasonal rainfall and the Yangtze River Basin

The Yangtze River is the world's third longest river spanning 3,900 miles. Intense or prolonged periods of rainfall in the region can lead to fl ooding and signifi cantly impact livelihoods. To help manage river levels, the river has hydroelectric dams which can be operated to withhold or release large quantities of water and control the impacts of fl ooding and drought downstream. The dams also rely on seasonal rainfall to produce electricity for provinces and major cities in eastern and southern China and managers of the dams can regulate electricity supply by controlling the river water level.

International collaboration

Through the CSSP China project, researchers in the UK and China have jointly developed a seasonal rainfall forecasting service for the Yangtze River Basin. In late 2015, researchers identifi ed that the Met Offi ce seasonal forecasting system has signifi cant skill in forecasting the variability of monsoon rainfall in the region, which is dominated by the infl uence of the El Niño Southern Oscillation (ENSO). Strong El Niño events tend to lead to above-average rainfall and fl ooding in the Yangtze River Basin in the following summer.

The researchers then worked in collaboration with decision makers to develop a prototype service that delivered forecasts of summer rainfall for the Yangtze River Basin up to a month in advance. The first trial forecast was issued in 2016 and was trialled by collaborators at the China Meteorological Administration (CMA) and water management organisations in the Yangtze Basin, including the Three Gorges Dam operators, whom CMA advise.

Impact of the seasonal rainfall forecast service

Users of the service have highlighted how it has helped them develop flood control plans that prevented flooding and avoided agricultural losses. The researchers are still advancing the service and in 2022 they found that there is good skill for forecasts of the likelihood of enhanced or reduced monsoon rainfall for the May, June, July period as far as six months in advance. The researchers are now looking at trialling this extension to the range of forecasts in the future.

> *"As a researcher, this project has given me a much deeper understanding of how stakeholder requirements can be integrated into climate service development, which has informed other work I've done, for example with the energy sector in the UK."*
>
> **Philip Bett, Senior Scientist, Met Office**

Met Office

At the forefront of weather and climate modelling

Weather and climate models are essential for producing weather forecasts and studying the impacts of climate change. These computer models solve complex mathematical equations to provide a representation of the weather and climate in the real world.

By bringing together global experts in weather and climate model development, the WCSSP Programme has made significant advancements to global modelling capability.

CSSP China | WCSSP India

Advancing the simulation of clouds to improve rainfall predictions

Clouds play a key role in the weather and climate system, redistributing heat and moisture through the atmosphere, producing rain, and reflecting sunlight back out to space. It is extremely challenging to accurately represent clouds in weather and climate prediction models due to the complexities of cloud formation. Researchers working on the WCSSP India and CSSP China projects have made significant progress in this area, delivering one of the most significant upgrades to the physics of the Met Office Unified Model (UM) in the last two decades. The UM is a numerical model of the atmosphere used for both weather and climate applications by a large global community of partners.

Evaluation work has shown this change has improved predictions of rainfall, showing better agreement with radar observations. This upgrade is helping to improve the accuracy of weather prediction and warnings of extreme rainfall as well as more robust projections of climate change.

> *“Based on these state-of-the-art climate models, we can further understand the sources of uncertainties in climate projections and find ways to make climate projections more reliable, which ultimately improves the usefulness of climate change information for aiding decision-making.”*

Dr Wenxia Zhang, Institute of Atmospheric Physics, China

Development of high-resolution modelling capability

Researchers are focusing on several areas to improve weather and climate modelling. One of these is increasing the resolution of models to kilometre and sub-kilometre scales to capture processes in the atmosphere and oceans that occur on small scales.

Collaborative efforts between all WCSSP projects have led to the development of world leading modelling systems at kilometre scales. These high-resolution models are providing improved forecasts on small-scale weather phenomena such as severe storms.

Their use in South Africa during Tropical Cyclone Eloise in 2021, allowed targeted weather warnings to be issued which prompted better preparedness contributing to reduced impact on people and property. “The development of a high-resolution modelling capability across weather and climate timescales supported by WCSSP Projects is contributing towards the wider international collaboration for improving model performance, benefitting operational and research centres around the world” Cath Senior, Met Office Principal Fellow.

Met Office

Reducing wildfire risk

Wildfires are unplanned and uncontrolled fires that can have devastating impacts on society and ecosystems. To improve our understanding on the risks from wildfires, researchers from the CSSP Brazil project are studying what causes wildfires in South America and how they may change in future. Through the project, our Brazilian partners have developed a fire probability forecasting service for South America to provide decision makers with information on the fire probability associated with South America's protected areas several months in advance.

CSSP Brazil

How are wildfi res changing?

In comparison to landscape fi res that are a natural process and vital for the health of many ecosystems, wildfi res are fi res that can burn out of control and have serious negative environmental, economic and social impacts. Wildfi res can destroy forests and infrastructure and their smoke can lead to poor air quality and contribute to climate change.

A 2022 report from the United Nations Environment Programme highlighted that the risk of wildfi res in many regions is increasing due to factors such as changes in land use and climate change. Fire weather, when conditions are advantageous to fire ignition and spread, has increased in most regions in recent decades due to climate change. Many areas have seen changes in the locations of wildfires and the lengthening of fire seasons. In South America, the fire season length has increased by an average of 33 days in the last 35 years.

Wildfi res and the global carbon cycle

When vegetation burns it releases large quantities of greenhouse gases into the atmosphere. As the Amazon rainforest is one of the world's largest and most important carbon stores, the increase in fi re activity in South America could impact the global carbon cycle.

CSSP Brazil research led by the Met Offi ce in collaboration with Brazil's National Centre for Monitoring and Early Warning of Natural Disasters (CEMADEN), used climate models to study how much carbon loss could occur in South America due to wildfi res.

Chantelle Burton, Senior Scientist at the Met Offi ce commented, "We found that burned area and fi re emissions are projected to increase in the future due to hotter and drier conditions, leading to a reduction in carbon storage."

Burnt trees and vegetation after a fire in Mato Grosso, Brazil. Image credit: Liana Anderson

Research found that in a scenario where the world continues to rely on fossil fuels leading to an average global temperature rise of 4º C, wildfi res could cause up to 30% of the carbon stored in South American vegetation to be released into the atmosphere, contributing to climate change. This loss of carbon could be reduced to 7% if the global increase in temperature is limited to 1.5ºC.

Developing a seasonal fire probability forecast for South America

One of the successful outcomes of the CSSP Brazil project has been the development of a seasonal fire probability forecasting service for South America. Led by CEMADEN in collaboration with the Met Office and the Instituto Nacional de Pesquisas Espaciais (INPE), the project used the Met Office seasonal forecast to analyse temperature and rainfall probability, together with fire trend data, and developed a method of calculating fire probability for South America several months ahead.

The researchers used the seasonal forecast to produce reports for decision makers on fire probability for South America's protected areas which have high biological, environmental and sociocultural value. Reports are also produced on fire risk to Brazilian municipalities. The forecasts are presented by CEMADEN in regular meetings to firefighters, civil defence workers and other stakeholders in Brazil and the forecasts have been shared with over 130 different organisations in Brazil.

Through identifying areas with increased fire probability and providing recommendations to mitigate that risk, the project is helping generate information to support wildfire strategic prevention and planning that will support conservation strategies across South America. The fire probability forecast has been incorporated into the operational plan for preventing and combating forest fires in the Amolar network - a network of protected areas in Pantanal. This network spans national borders, facilitating strategic planning and fire management across the region.

"The forecast is being used by the Brazilian states of Goiás, Maranhão and Mato Grosso do Sul to guide prevention and mitigation actions. Since August 2021, more than 70 protected areas have received a 'high alert' level and more than 1800 at an 'alert' level, meaning areas are threatened by fire."

Liana Anderson, CEMADEN

Map of the seasonal fire risk forecast for protected areas in South America for August to October 2022

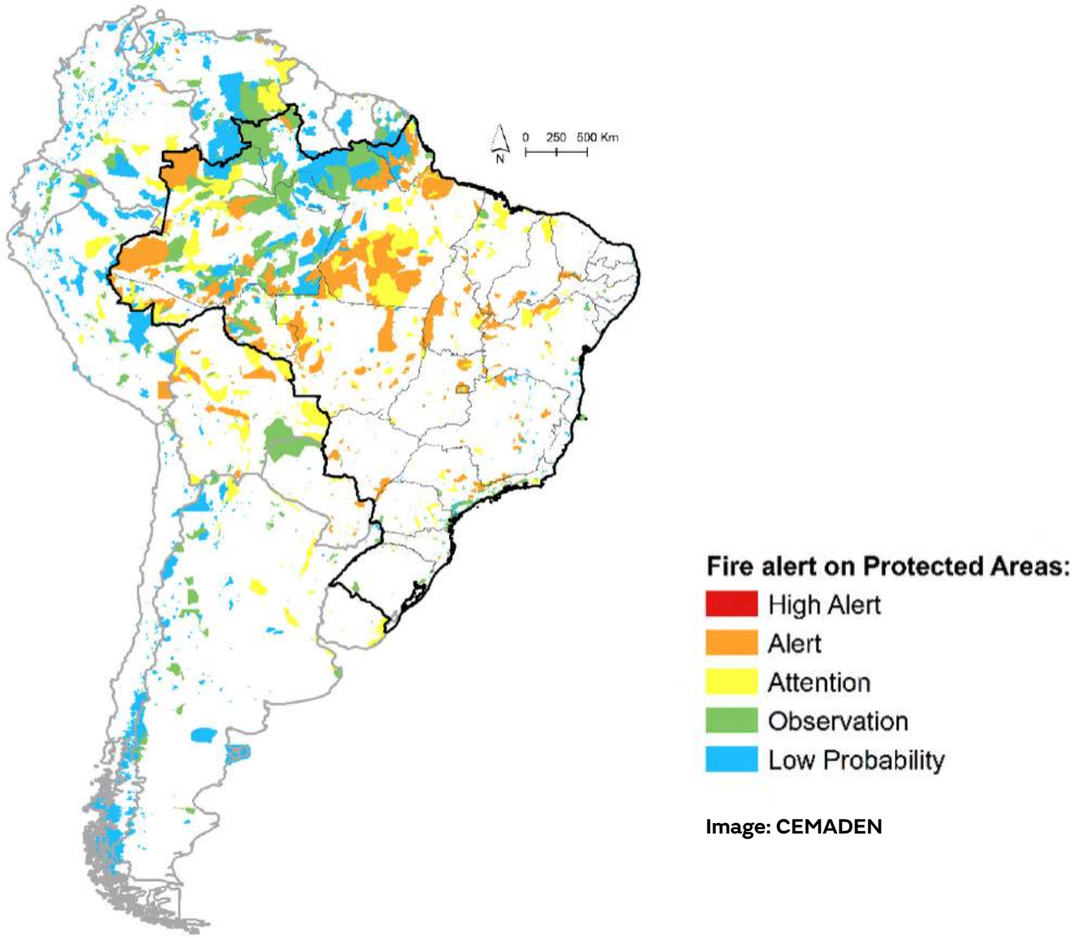


Image: CEMADEN

Met Office

Improving coastal resilience

Millions of people around the world live in coastal regions. Coastal communities are not only impacted by natural hazards such as rip currents, but they are also faced with the impacts of climate change through sea level rise and flooding. Due to strong international collaboration, the WCSSP South Africa project is improving our understanding of risks to coastal regions in addition to developing key services that can protect lives from coastal hazards.

WCSSP South Africa

Developing rip current warnings

One of the key outputs of the WCSSP South Africa project has been the development of warnings for rip currents in South Africa. Rip currents are strong hazardous currents that run out to sea and cause hundreds of coastal drownings each year around the world. They are one of the biggest dangers facing beach users in South Africa.

Research has shown that rip currents are strongly related to wave and tide conditions, often making them predictable. The ability to predict when and where rip currents will occur, and when they are most active, provides an opportunity to warn beach users and coastal lifesaving organisations of the times and locations with the highest risk.

International collaboration

To reduce the impact of this hazard, an international collaborative project involving the University of Plymouth and South African Weather Service (SAWS) developed forecasting tools for rip current hazards in South Africa. Collaboration has been essential for this work and with support from the National Sea Rescue Institute, City of Cape Town, Stellenbosch University, and Lifesaving South Africa, the project was able to bring together sea rescue incident records, wind, wave and water level forecasts as well as the results of field experiments.

A pilot operational rip risk hazard forecast for the Cape Peninsula coastline was developed and trialled in June 2021 to warn the public of the risk of rip currents. During the trial, the forecast was used to safeguard members of the public and prepare emergency services.

Validation of the model is currently ongoing to have the forecast running operationally by the end of 2023 when forecasts will be generated daily using the SAWS marine forecasts and provide rip risk forecasts for the following three days. Future work also hopes to extend this forecast to other locations in South Africa.

Rip current in South Africa. Credit: Carla-Louise Ramjukadh

> *“It is great to see our research being put into action by South African Weather Service through the pilot operational rip forecast. The forecast brings together vital elements needed to predict when rip currents will be most hazardous, including analysis of past lifeguard incidents and modelling and measurements of wave and tide conditions.”*

Dr Christopher Stokes, University of Plymouth

Met Office

Improving coastal resilience

Forecasting coastal overtopping

Over the past century, global mean sea level has risen by around 20 cm due to global warming. Higher sea levels amplify the effect of high tides and storm surges increasing the risk of coastal inundation and the overtopping of both natural and man-made coastal defences.

To help prepare for these events, the University of Plymouth in collaboration with SAWS and the University of Stellenbosch developed a pilot overtopping forecast service which is being trialled in Cape Town. Advanced warning of hazardous conditions will enable warnings to be issued to decision makers, such as local governments and emergency services, who can then determine whether actions such as evacuations or temporary flood defences are required. Through the development of this forecast, coastal flooding hotspots have also been identified enabling strategic adaptation decisions to be made. SAWS are currently in the process of operationalising this forecast for the Cape Town region.

> *"The value of a coastal overtopping forecast is very important and plays a vital role in forewarning communities and public safety personnel to better prepare for the potential forecasted risk and hazardous conditions."*
>
> **Carla-Louise Ramjukadh, South African Weather Service**

Developing a sea level rise climate service

Since the 1960s, the rate of sea level rise has increased and global mean sea level is currently rising by 3 mm every year. It is virtually certain that it will continue to rise until at least 2100, increasing coastal flood risk for millions of people around the world.

To adapt to rising sea levels, decision makers need regionally specific information on future sea level rise. Research led by the Met Office explored current and future sea level rise at eight sites around the coast of South Africa. Future projections of sea level rise in a low and high greenhouse gas emission scenario suggest South Africa will experience 7-14% greater increases compared to the global mean sea level due to a range of factors such as changes in ocean currents.

The researchers also carried out preliminary estimates of the height by which coastal defences must be raised to maintain the same level of protection in the future as they do in the present day. They found that by 2100, for the lower emission scenario the required rise in South Africa is 0.6 m and for the high emission scenario coastal defences would need to be raised by up to 1.2 m.

The project has used the findings of the study to develop one-page summaries for the eight sites. These have been shared with local stakeholders, including coastal engineers and coastal planners in the City of Cape Town municipality and KwaZulu-Natal.

Credit: Diego Delso, delso.photo, License CC-BY-SA

Developing new weather forecasting tools

Weather patterns describe the dominant characteristics associated with particular conditions such as wet or dry weather. The WCSSP India project has developed a new weather pattern forecasting tool that has the ability to provide an earlier assessment of the potential impacts from extreme weather events, which could help save lives and livelihoods.

WCSSP India

Studying weather patterns

Weather patterns can characterise the dominant conditions associated with different types of weather in a particular region, such as wet or dry, which can give an indication of risk of associated hazards such as flooding or landslides. Every location has its own unique set of weather patterns which represent the typical climate in that area throughout the year. Each weather pattern can also be linked to specific impacts on different sectors such as agriculture, energy or transport. If these patterns are predictable in advance then warnings of these impacts could be given ahead of time and earlier than typical weather forecasts.

New weather pattern tool applied over India

The WCSSP India project identified a set of 30 weather patterns for India and has shown they can all be skilfully predicted up to two weeks in advance.

Robert Neal at the Met Office explains “We looked back at the devastating floods in Kerala in August 2018 to see if a new tool we were developing could have given us an indication of what was going to happen. It showed that 10 days ahead of the event it was forecasting a weather pattern associated with high levels of rainfall in the region.”

The project also looked back at another case study, the flooding in Mumbai in September 2018. Again, this new tool showed that a weather pattern associated with heavy rainfall in the Mumbai region was most likely 10 days ahead of the event. The forecasting tool has now been shared with WCSSP India partners who are using it with their own weather forecasting models.

The WCSSP programme is now exploring the application of this tool to benefit other regions around the world such as Southeast Asia, South Africa and Brazil.

“These weather pattern forecasts are very useful as they can be related to the likelihood of some disastrous events coming up in the medium-range period. The final output of this new tool is simple and can easily be transmitted to end users.”

Dr Ashis Mistra, former head of the National Centre for Medium Range Weather Forecasting (NCMRWF)

Met Office

Advancing impact-based forecasting

Impact-based forecasting warns communities of the impacts associated with extreme weather and is considered best practice by the World Meteorological Organization, who have an initiative to ensure early warning systems reach every person on Earth by 2027. Through strong international partnerships, the WCSSP programme is supporting the roll out of impact-based forecasting systems which is complementing the recommendations of the World Meteorological Organisation.

WCSSP South Africa

What is impact-based forecasting?

While traditionally weather forecasts have given an indication of what the weather will be, impact-based forecasting considers the vulnerability of people and property and warns of what the weather will do and what the impacts might be.

Impact-based forecasting enables an integrated, authoritative message to be delivered to all parts of society so that everyone can take appropriate action to ensure personal safety and protect property.

Impact-based forecasting in South Africa

The WCSSP South Africa project has been working with the South African Weather Service (SAWS) to launch a new impact-based severe weather warning service in South Africa, which has already delivered significant benefits.

The project hosted outreach workshops where communities were invited to attend and develop communication chains with the National Disaster Management Centre. This ensured that warning messages will be understood and communicated to those who need it to ensure that appropriate actions can be taken. Forecasters also received training to ensure non-scientific terminology is used when communicating forecasts and warnings.

Read the full case study on the **Met Office website**

Impact-based forecasting outreach workshop at East London, Eastern Cape, February 2019 Credit: Met Office

Successfully launching a new service

The new service started issuing warnings to the public in October 2020. In January 2021, SAWS issued the highest possible warning for disruptive rain ahead of tropical cyclone Eloise which then led to landslides and significant damage to infrastructure. Feedback from members of the National Disaster Management Advisory Forum in addition to disaster managers in Limpopo and Mpumalanga showed the warnings were understandable and provided sufficiently ahead of time so people could take action to reduce the impact of the severe weather.

Decisions and actions made because of the warnings included pre-emptive evacuations, placing emergency teams on standby, moving livestock and animals away from rivers, staying at home and readying sandbags. The lessons learned through the implementation of the new system will be shared to benefit other countries across Southern Africa as they continue their journeys towards implementing impact-based forecasting.

> *"The new service provides communities with the information they need to respond appropriately which helps save lives."*
>
> **Vanetia Phakula, Senior Forecaster at the South Africa Weather Service**

WCSSP Southeast Asia

Sharing experiences of impact-based forecasting

The WCSSP Southeast Asia project has been conducting a range of activities to strengthen the ability of institutions to issue timely, accurate warnings of high impact weather. Activities include developing new visualisation tools to aid forecasters, evaluating the operational use of ensemble models which can improve understanding of the uncertainty of weather forecasts, and analysing the decision-making process that forecasters go through to issue high impact weather forecasts.

In addition to this, institutes from the UK, Indonesia, Malaysia, Philippines and Vietnam have shared their experiences of implementing impact-based forecasting so they can learn from each other. Through international collaborative workshops, over 200 scientists and operational forecasters in Southeast Asia have received training in impact-based forecasting.

Evaluating impact-based forecasting

The project has also developed an observation database which will allow partner countries in Southeast Asia to collect, analyse and compile impact data to undertake impact-based forecast evaluation. So far, the database has over 41,000 observation records for Southeast Asia between 1970 and present. Globally the evaluation of impact-based forecasts remains a challenge and the observational database being developed through WCSSP Southeast Asia will enable impact forecasts to be compared to what actually happened on the ground and improve the accuracy of future warnings.

Strengthening early warning systems

The WCSSP programme's work on impact-based forecasting has already had significant impacts with implementation in several partner countries. Through this work, local communities and stakeholders are gaining a deeper understanding of severe weather events, their potential impacts, and the importance of community planning to mitigate against high impact weather.

In the Philippines, the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) has been developing impact-based forecasting for the Metro Manilla and Metro Cebu pilot areas. Feedback from stakeholders and disaster managers has highlighted that impact-based forecasts are critical to improve early warning systems for the cities, and lead to an improved response to warnings that are issued. There has also been the successful development of impact-based forecasting procedures in Indonesia.

> *"In 2023 we are aiming to roll out the national implementation of impact-based forecasting to all provinces in Indonesia, which will lead to significant benefits and help improve preparedness for weather extremes by disaster managers and help protect lives and livelihoods"*
>
> **Dr Agie Putra, Agency for Meteorology Climatology and Geophysics of The Republic of Indonesia**

Met Office

Building climate resilient food systems

Agricultural systems are highly dependent on weather and climate. Through the WCSSP programme, researchers around the world are improving our understanding of the current and future climate risks to globally important crops including maize, tea and sugarcane. Researchers are also developing tools and services that can provide farmers and decision makers with the information they need to manage these risks and increase the resilience of these systems in the future.

CSSP Brazil

Monitoring agricultural drought risk

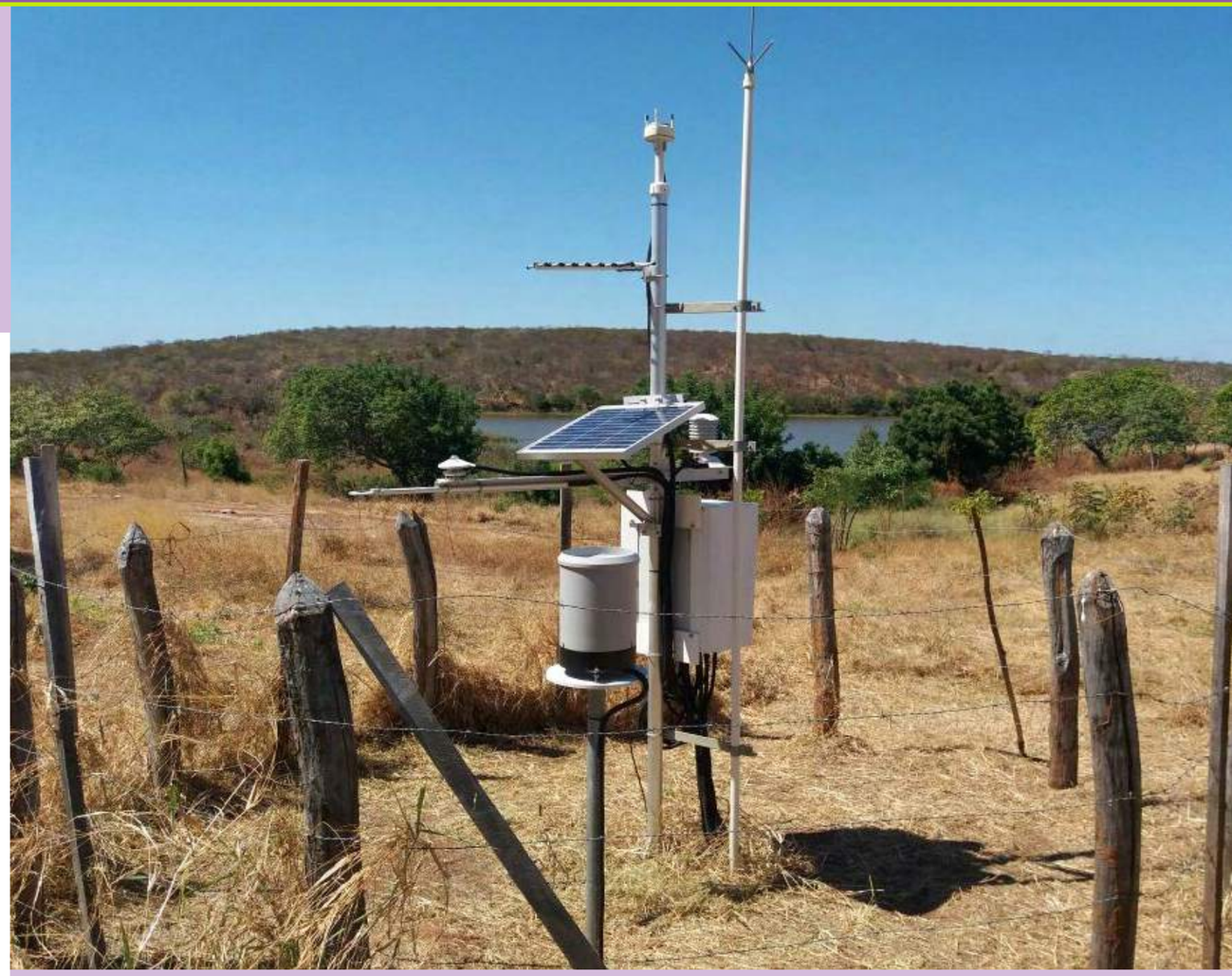
Agricultural drought occurs when a lack of soil moisture, either due to a shortage of rain or other factors, impacts agricultural activities such as crop growth. This can lead to a loss of food and income for agricultural communities and information on drought is vital to support agricultural decision making.

Drought can be monitored in several ways through sensors, satellites, or land surface models. A collaboration between scientists in Brazil and the UK has led to the production of a digital platform that provides information on regions in Brazil that are experiencing drought stress.

The platform uses data from satellites and weather stations to provide information for four different types of agricultural drought indices. The drought indices are produced by the National Center for Monitoring and Early Warning of Natural Disasters in Brazil (CEMADEN) which include the changes in rainfall, soil moisture in the root zone, and vegetation stress.

Users can look at the current month's data as well as historical data to visualize and understand the drought patterns of any given location in Brazil. The tool is designed to be used by a range of audiences, from agronomists and farmers to local and national policymakers.

Read the full case study on the **Met Office website**



Sensors are used to gather observational data to support drought monitoring in Brazil. Credit: José Maria Costa

> *Since the launch of the platform in January 2022, it has had over 150,000 views from over 6,000 unique users. Recent funding will allow us to expand the capabilities of this tool, exploring new applications of machine learning for drought forecasts.*
>
> **Marcelo Galdos, Senior Research Scientist, Rothamsted Research**

CSSP China

Supporting the global maize industry

Maize is an important global crop produced both for human and animal consumption. Maize relies predominantly on rainfall to grow, making production susceptible to climate hazards, such as drought. Unexpected decreases in maize production could negatively impact prices, trade, and global food security.

Researchers from the Met Office are working in collaboration with the Beijing Climate Centre to develop a prototype seasonal forecast for the climate impact on maize yield in northeast China, one of the world's key regions for maize production.

Maize yield at the province-scale is impacted by summer temperature and rainfall, with too much or too little having negative effects. Based on this relationship, scientists have developed a forecasting approach which identifies the likely impact of the observed summer climate on maize yields in each province.

The forecast can be issued in July, August, and September ahead of crop harvest in October and ongoing work is exploring approaches for extending the forecast lead time.

Andrew Cottrell, Senior Scientist at the Met Office commented, "This approach can help decision-makers understand and manage the climate risk to maize production in China at regional and national scales, potentially informing planning decisions."

Developing prototype forecasts

The first prototype forecasts were produced with colleagues at the Beijing Climate Centre in 2022. Further research is being conducted to look at extending the forecast so it can be issued earlier in the year to enable more proactive planning, and to investigate the potential impacts of climate change on maize yield in this region by the middle and end of the century.

Peiqun Zhang, Senior Scientist at the Beijing Climate Centre added, "We could apply the approach to explore a method for estimating the climatic growth of maize to help decision makers, including farmers, to counteract the risks associated with climate variability."

"The close collaboration we have built with scientists in China through the WCSSP Programme is enabling us to engage on various food security topics including maize, tea and oilseed rape. The work aims to benefit not only specific communities but also contribute to our wider understanding of the need for climate information for food security globally."

Nicola Golding International Climate Services Manager, Met Office

Training early career scientists

Supporting the development of early career researchers is vital to overcome current and future weather and climate challenges. As part of the CSSP Brazil and China projects, researchers in extreme event attribution have trained over 100 early career scientists to provide them with the skills and knowledge they need for conducting their own studies.

CSSP Brazil | CSSP China

Studying the influence of climate change on extreme events

Extreme event attribution investigates the influence of human-induced climate change on extreme weather events. Through using computer models, researchers can assess how climate change influenced the likelihood and intensity of an event. Through the WCSSP programme, over 100 early career scientists have been trained in extreme event attribution through a series of workshops held in Brazil and China. The workshops have also led to 12 peer-reviewed papers being published which detail the findings of the attribution studies conducted through the workshops.

The first workshops were held through the CSSP China project and led by the University of Edinburgh in collaboration with the China Meteorological Administration and several other institutes. The workshops provide scientists with the skills they need to conduct their own attribution studies and Prof. Simon Tett from the University of Edinburgh commented, “These workshops are a great demonstration of knowledge exchange. We bring state-of-the-art model data and techniques. The participants nominate the extreme events to be studied and bring scientific understanding of the weather drivers of the event. And it is great fun to work with so many talented scientists.”

Since then, the CSSP Brazil project has also hosted several workshops in Brazil. Dr Sarah Sparrow from the University of Oxford commented, “Being involved in running the CSSP China workshops provided me with a template on how to run a successful workshop that is not only engaging for the participants, but also for the tutors and workshop leaders involved. In the CSSP Brazil workshop we were able to demonstrate that the attribution workshop format developed in the CSSP China projects could be successfully extended to include training on disseminating results.”

Led by CEMADEN and the University of Oxford in collaboration with the University of São Paulo, the Met Office and other research institutes, the CSSP Brazil workshops have helped uncover information about how the risks of certain extreme events have changed due to climate change.

Climate change and extreme rainfall in Brazil

One of the CSSP Brazil workshops focused on an extreme rainfall event in 2020 in southeast Brazil that led to flooding and landslides. The researchers found that human-induced climate change made this event over 70 times more likely to occur. Due to the event, at least BRL 1.3 billion (USD 240 million) was lost in the public and private sectors and the researchers estimate that 41% of this could be attributed to human-induced climate change. After the workshop, participants and tutors published a collaborative paper detailing the outcomes of the study. In total, 12 internationally collaborative papers have been published as a result of the China and Brazil workshops.

> *“We have extreme weather events in Brazil every year, and our attribution studies are not only showing that the effects of climate change are already here but can also provide policy makers with valuable information on current and future risks from climate change.”*
>
> **Dr Ricardo Dalagnol, University of California Los Angeles, previously Brazil’s National Institute for Space Research (INPE)**

Met Office

Studying the links between air quality and climate

Poor air quality is one of the largest environmental risks to public health. The World Health Organisation estimates that exposure to outdoor air pollutants are associated with four million premature deaths every year around the world. Research led by the Met Office, as part of the CSSP China project, is investigating the impact of future changes in air pollutants on air quality and the climate.

CSSP China

The links between air quality and climate

Air pollution is linked to the Earth's climate. Several of the drivers of air pollution, such as the combustion of fossil fuels, are also sources of greenhouse gas emissions. Some pollutants can also influence the climate, for example ozone traps heat in the lower atmosphere, adding to the already enhanced, human-induced greenhouse effect. In contrast, tiny air pollution particles which are also known as aerosols, can have a cooling effect on the climate by reflecting sunlight back out to space.

Pioneering research

Through the CSSP China project, researchers are studying how changes in atmospheric compounds could influence air quality and climate. The researchers focused on compounds such as methane and ozone which are known for being short-lived because they are produced and removed in the atmosphere over much shorter timescales when compared to the long-lived greenhouse gases such as carbon dioxide. Using a global earth system model, the researchers compared a selection of future mitigation scenarios to understand how changes in these compounds influenced the rate of climate warming and air quality.

> *"We found that simultaneously reducing concentrations of methane and aerosols would lead to the largest benefit to both future climate, air quality and human health, particularly across Asia."*

Dr Steven Turnock, Met Office Senior Scientist

However, the relationship between these atmospheric pollutants and climate and air quality is complex. The researchers found that if only aerosols are reduced, then this leads to a benefit to air quality but could result in detrimental impacts on climate. The results of the study provide useful insight which could be used to inform future policy decisions and mitigation planning.

Delivering impact

Other air quality research part funded by CSSP China has impacted policy reports including the WMO Air Quality and Climate Bulletin and the European Commission's report on Global trends of methane emissions and their impacts on ozone concentrations.

Steven added "Our findings highlight that reducing different short-lived atmospheric pollutants can have different impacts, particularly regionally, and that measures to benefit both future climate, air quality and health need to be carefully designed".

Met Office

You can find more details on the Met Office website or contact us at:

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