NOVEMBER 2015

AllEnvi

French Alliance for Environmental Research

60 RESEARCH SUCCESS STORIES FOR A SUSTAINABLE PLANET

PROTECTING THREATENED BIODIVERSITY

FEEDING THE WORLD

PROTECTING THE SEAS AND OCEANS

MANAGING WATER RESOURCES

LAND DEVELOPMENT AND PLANNING

ANTICIPATING CLIMATE CHANGE RISKS

MOBILIZING RESEARCHERS FOR THE CLIMATE AND THE ENVIRONMENT

COP21 · CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

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The global challenge of climate change calls for the strong, broad and open mobilization of the scientific community.
The 12 founder members and 16 associate members of AllEnvi represent a community of nearly 20,000 scientists. AllEnvi covers all areas of environmental research and is actively involved in the European Research Area (ERA) and major international initiatives. It therefore brings together a remarkable level of multi-disciplinary and systemic expertise to issues regarding climate change, its causes, its cascading impacts and strategies for combating it.

AllEnvi

www.allenvi.fr French Alliance for Environmental Research

CONTENTS

60 RESEARCH SUCCESS STORIES FOR A SUSTAINABLE PLANET

EDITORIAL

How French research is mobilizing to confront climate change

The international scientific conference Our Common Future under Climate Change that took place in July 2015 in Paris clearly confirmed that climate disruption is real, with its cascade of impacts and the increasingly urgent need to propose sustainable solutions.
Food, natural resources, biodiversity, and land management are major issues: how will it be possible to feed more than 9 billion people by 2050, ensure access to adequate clean water, reduce greenhouse gases emissions, adapt urban planning and design new land management strategies?
The role of research in these issues is essential in describing, diagnosing and understanding systems and their mechanisms, developing technologies, adapting our organizations and innovating, raising social awareness and offering sustainable solutions. In the context of the forthcoming COP 21, which is taking place in Paris in December 2015, French public research is mobilizing under the banner of AllEnvi to better understand and combat climate change. ***The AllEnvi Alliance is publishing this exceptional work in the form of a 64 page magazine called 60 Research Success Stories for a Sustainable Planet.*** *From the Alliance's scientific successes, the editors have selected examples providing a good overview of the work conducted. This provides readers with insight into the exceptional mobilization of French scientists in pooling their inter-and multi-disciplinary expertise.*

The members of AllEnvi

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RESEARCH IN ACTION
FOUR MAJOR CHALLENGES
FOR A SUSTAINABLE PLANET

In a context of global climate change, awareness of limited resources presents major challenges at the international scale. Through the AllEnvi alliance, French environmental research is mobilizing to confront the major societal issues that this raises. The challenges in pictures.

FOOD SUPPLY

Feeding nine billion people by 2050

Our agricultural and food supply systems contribute to climate change, and are also affected by its direct impacts. New forms of agriculture and livestock rearing could feed the world while promoting biodiversity, reducing greenhouse gases emissions, and even absorbing CO_2.

Cereal harvest. © Gérard Paillard/INRA

Researchers are helping farmers produce 'more and better' to feed 2 billion extra people by 2050.
© IRSTEA

Sustainable aquaculture production systems must be implemented to meet the growing demand for aquatic products.
© Christophe Maître/INRA

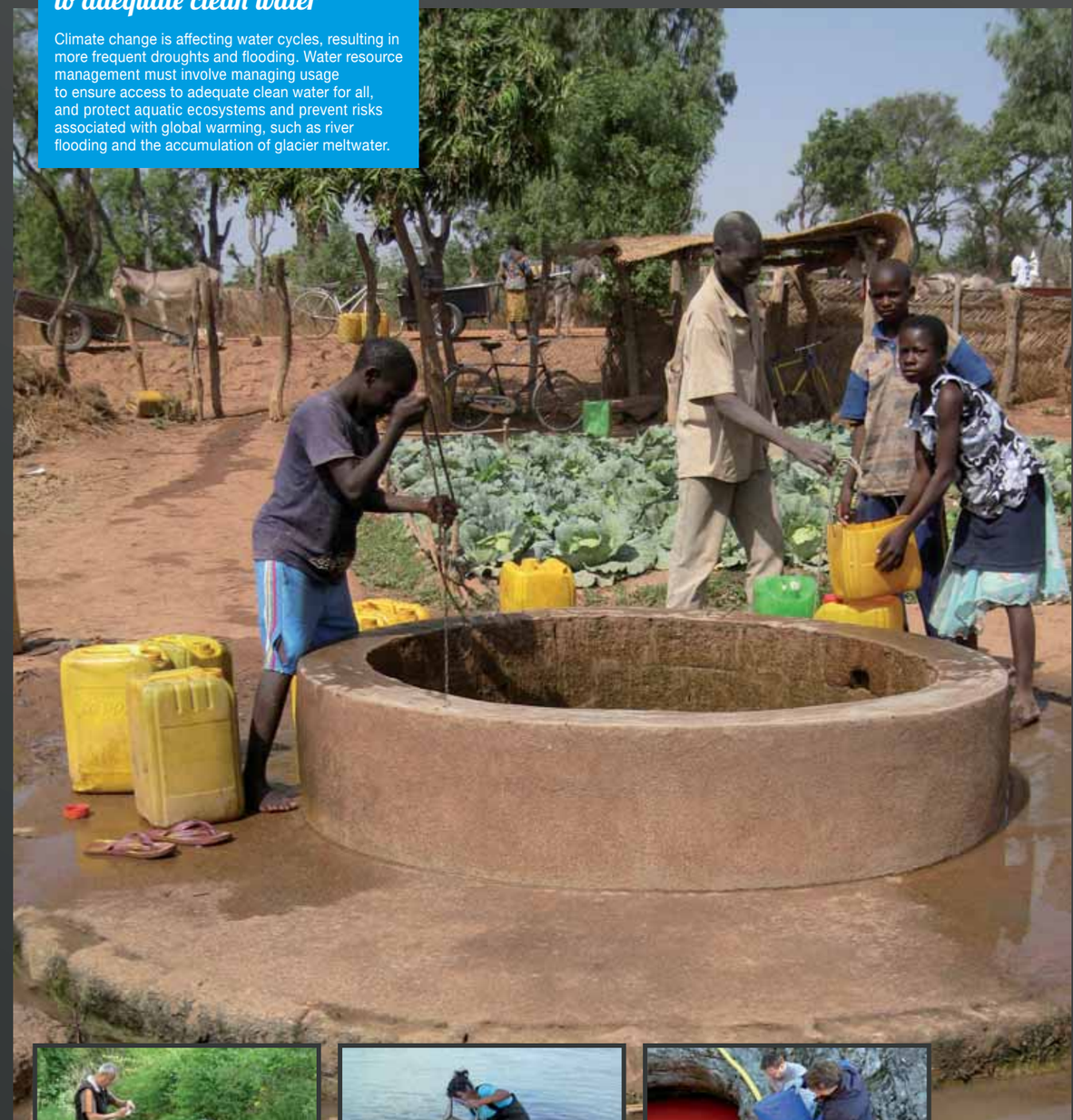
Scientist are breeding varieties of cultivated plants that are better adapted for future climate changes.
© Sylvie Toillon/INRA

WATER AND RESOURCES

Ensuring global access to adequate clean water

Climate change is affecting water cycles, resulting in more frequent droughts and flooding. Water resource management must involve managing usage to ensure access to adequate clean water for all, and protect aquatic ecosystems and prevent risks associated with global warming, such as river flooding and the accumulation of glacier meltwater.

Young people in Burkina Faso collecting water from a well in plastic containers to water their vegetable crops. © Marie-Noëlle Favier/IRD



Rising temperatures and water demand for various uses mean that adaptation strategies must be planned in advance.
© BRGM

Maintaining water quality is a crucial challenge in a context of global warming and increasing pollution.
© Gait Archambaud-Suard/IRSTEA

Injecting a tracer to monitor groundwater flow to characterize karst systems.
© BRGM

CLIMATE

Predicting climate change to better adapt

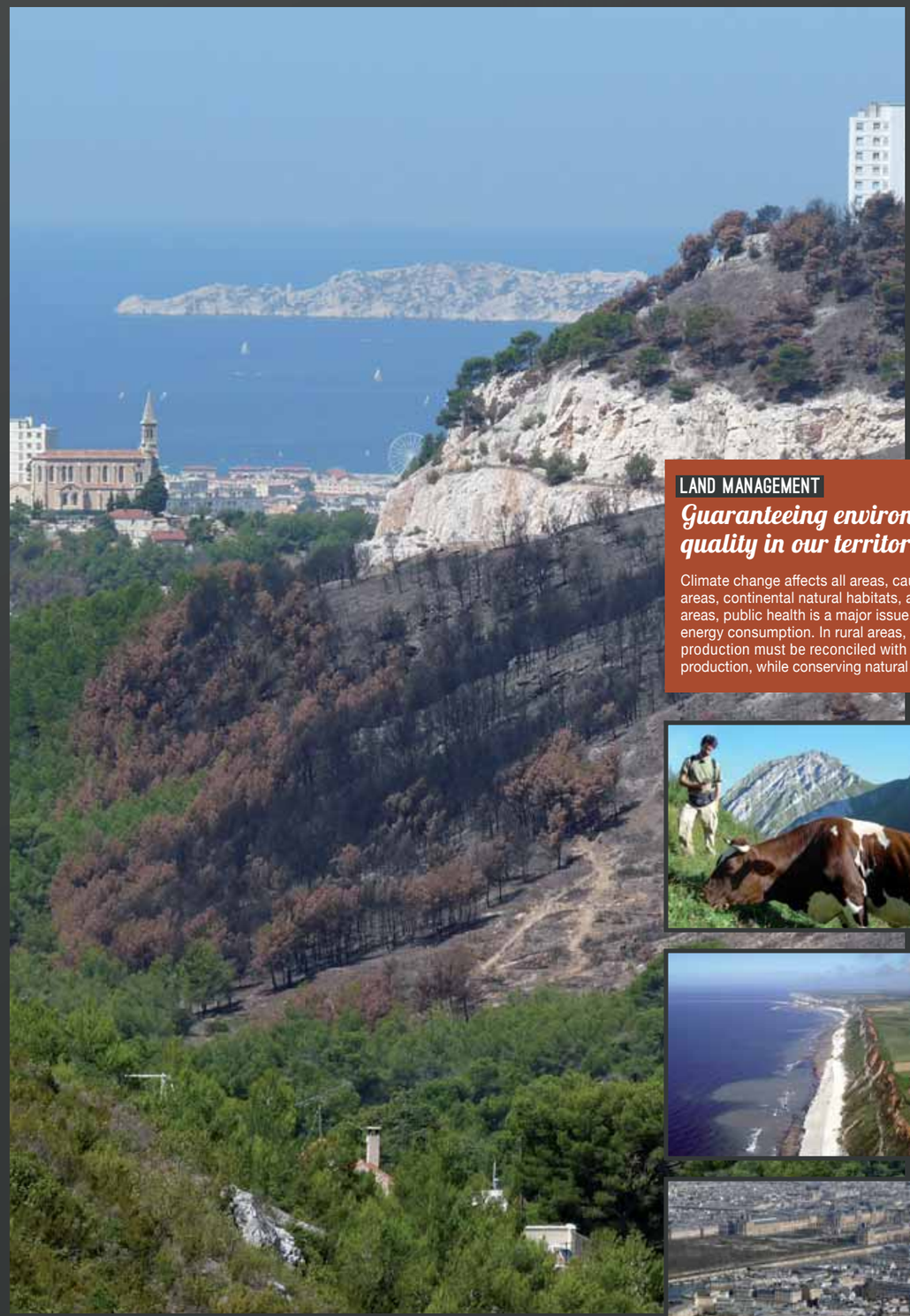
Rising temperatures and changes in rainfall patterns will have an impact on many aspects of the Earth including soil, air and water. Climate change will thus affect the entire biosphere, including people, and cause much disruption. Climate change is manmade: it is urgent that we agree on measures for adaptation and reducing greenhouse gases emissions.

Cracked earth and vegetation regrowth in the Australian outback. © Alain Rival/CIRAD

Coral bleaching: by 2040, three-quarters of the planet's reefs could suffer from this phenomenon caused by global warming!
© Thomas Vignaud/CNRS Photothèque

The Glacioclim observation network provides information to gain a better understanding of climate-glacier relationships and their future changes.
© Patrick Ginot/IRD

Emerging infectious diseases, such as leishmaniasis and chikungunya, could become more numerous due to global warming.
© Vanina Guernier/IRD



Damage observed in the built environment in Marseille following the wildfire on 22 and 23 July 2009.
© Marlène Long/IRSTEA

LAND MANAGEMENT

Guaranteeing environmental quality in our territories

Climate change affects all areas, causing changes to coastal areas, continental natural habitats, agriculture, etc. In urban areas, public health is a major issue, along with overall energy consumption. In rural areas, agricultural food production must be reconciled with various forms of energy production, while conserving natural habitats such as forests.

Mountain regions are more affected than plains, with higher than average temperature increases.
© Michel Meuret/INRA

Rising sea levels and more powerful storms threaten coastal areas such as the Seine-Maritime cliffs.
© Guillaume Bertrand/BRGM

Research measures the impact of climate change on various urban developments, providing precious data for urban planners.
© Pascal Taburet/Météo-France

CLIMATE CHANGE: CONCRETE SOLUTIONS FOR IMPACTS THAT CAN ALREADY BE FELT

© Ch. Maître/INRA

“Environmental research is essential to raise social awareness, stimulate the economy, and offer sustainable climate change solutions.”

By François Houllier, *Chairman of AllEnvi*

Our societies are confronted by unprecedented global changes, and particularly climate change. The institutions which have been working together under the AllEnvi banner since 2010 to coordinate environmental research (food, water, climate and land management) have focused their research on climate change for many years.

Rising to the climate challenge, members of the alliance share 60 of their research success stories in this publication.

During COP 21, political leaders will attempt to reach a consensus and act to limit greenhouse gases emissions, which are at the root of climate disruption. The Intergovernmental Panel on Climate Change (IPCC) sounded the alarm several years ago, and French research has actively contributed to producing increasingly precise knowledge on the causes, mechanisms and impacts of climate change.

However, the role of scientists is not limited to sounding alarms. They have been working for a long time to develop solutions to mitigate and adapt to climate change in every area. *60 Research Success Stories for a Sustainable Planet* bears witness to this effort. The scientific research from AllEnvi members contributes to public policy as well as innovation and value creation. The social and economic benefits from this research are tangible. Sustainable management of water resources, optimization of methane production from bio-waste, improvements to forestry management, and models and decision support systems to help better monitor crops and prevent food crises are just a few concrete examples of the results from research that you will discover in this collection. //

QUOTES

BIODIVERSITY, A FUNDAMENTAL ISSUE

Understanding biodiversity's response to climate change is a fundamental issue, because its properties, ecological functions and adaptive potential are the basis of the values and wealth of societies. For this reason, it is imperative to observe its responses and study its mechanisms.

Bruno David, Chairman of the French Natural History Museum (MNHN)

FOCUS ON FOOD SECURITY

AGRICULTURE MUST CONTRIBUTE TO THE AGENDA OF SOLUTIONS TO RECONCILE THE FIGHT AGAINST CLIMATE DISRUPTION WITH FOOD SECURITY: IT IS A MAJOR ISSUE FOR GLOBAL AGRICULTURAL RESEARCH

François Houllier, CEO of the French Institute for Agricultural Research (INRA)

The South is a priority

Combining the fight against climate change with sustainable development is a top priority for research in developing countries, to reconcile climate change mitigation and adaptation, environmental protection and reducing inequalities.

Jean-Paul Moatti, CEO of IRD (the French institute for research for development)

TOWARDS NEW CLIMATE SERVICES

OUR CHALLENGE IS TO PREPARE THE EMERGENCE OF CLIMATE SERVICES, COMBINING KNOWLEDGE ACQUIRED REGARDING CLIMATE AND THE NEEDS OF VARIOUS CATEGORIES OF USERS, AND OFFER SUPPORT TO CLIMATE CHANGE ADAPTATION POLICIES.

Jean-Marc Lacave, CEO of Météo-France (the French meteorological office)

THE SUBSOIL: AN ASSET IN THE FACE OF CLIMATE CHANGE

Underground technologies serving the energy transition are also used to adapt to climate change: observing and understanding its effects on coastal erosion, groundwater resources, ground shifts…in order to then develop multi-risk analyses leading to new local and regional strategies.

Vincent Laflèche, CEO of the French Geological Survey (BRGM)

SUSTAINABLE LAND MANAGEMENT

ONE OF THE CHALLENGES OF CLIMATE CHANGE IS TO SET COUNTRIES ON THE PATH TO SUSTAINABLE DEVELOPMENT. THE CONSEQUENCES FOR RESEARCH ARE FOUND IN THE COMPLEX CHANGES OF SCALE THAT THIS ENTAILS.

Jean-Marc Bournigal, CEO of the National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA)

We need low-carbon mobility

Climate change calls for sustainable local development and for development of low-carbon mobility. The complexity of the issues means that a cross-disciplinary partnership approach is needed, covering both technological problems and behavior-and use-related issues.

Jacques Tavernier, Chairman of the Board of the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR)

Joint mobilization

Reviewing existing development models, and integrating environmental responsibility and citizenship into all our decisions and actions involves major issues and an is ambitious challenge in terms of the training and research associated with climate change in French universities. We are working together to protect our planet and future generations.

Jean-Loup Salzmann, President of the Conference of University Presidents (CPU)

AN ACTIVE CONTRIBUTION TO THE ANALYSIS OF CLIMATE CHANGE

The research of the CEA and its partners on how the global climate system works and the impact of its changes on the planet contributed to the fifth IPCC report. The CEA also performs research to develop low-carbon energy and improve energy efficiency.

Daniel Verwaerde, General Director of the French Alternative Energies and Atomic Energy Commission (CEA)

Oceans at the heart of the system

Oceans are central to the 'climate system'. In the coming years, one of the challenges is to better understand how species adapt to changes in water masses by migrating towards the poles or by changing their routes.

François Jacq, CEO of the French Research Institute for Exploitation of the Sea (IFREMER)

Agriculture is directly concerned

Agriculture both contributes to and is impacted by climate change. It is therefore directly concerned in the fight against it. Agricultural research must go beyond studying impacts to also target mitigation and adaptation.

Michel Eddi, CEO of CIRAD (the French agricultural research organization working for development)

SCIENCE AT THE OUTPOSTS

The 21st Conference of Parties on climate change (COP 21) is an opportunity for scientists who are working to understand the mechanisms of climate change, and assess its consequences and impacts, to take centre stage. From social to earth sciences, from ecology to engineering, CNRS is mobilizing its institutes to offer and share their knowledge within the scientific community and with all areas of society.

Alain Fuchs, President of the French National Centre for Scientific Research (CNRS)

CUT GREENHOUSE GASES EMISSIONS BY 75%

In 2013, the French government committed to reaching this target by 2050. Backed by the findings of the IPCC and a mission assigned to climatologist Jean Jouzel by the French Ministry of Ecology, France's climate change strategy includes major research work and observational infrastructure. It is a joint project led by members of the AllEnvi alliance.

In the long term, every country will be affected by global warming. Based on IPCC scenarios and the national implications identified by climate specialists, French research, particularly through the AllEnvi alliance, has been working on major initiatives. One of the key challenges is to cut greenhouse gases emissions by 75% by 2050.

From understanding climate mechanisms to developing detailed models

Research is bringing innovations to the highest emissions-producing sectors, particularly the key construction and transport sectors, to develop more autonomous housing and cleaner modes of transport. Research is also making advances to cut greenhouse gases emissions more quickly in other sectors such as industry, agriculture and the exploitation of the oceans.

From a scientific perspective, however, the environmental urgency is helping to drive the research agenda, with the following goals:

→ **Understanding and modelling climate change** through observation and simulation.

→ **Understanding the reaction of living organisms** to climate change in interaction with human activities, and to better protect them.

→ **Developing innovations, and green technologies and design** to manage greenhouse gases-producing activities more effectively and design competitive products and services that have little or no environmental impact.

→ **Ensuring a carbon-free energy future.**

Various alliances, including AllEnvi (French Alliance for Environmental Research) and ANCRE (French National Alliance for Energy Research Coordination), are responsible for implementing this strategy.

A global observation system

France is involved in global observation programmes and participates in the Global Climate Observing System (GCOS – see the graphic on p14). All members of the AllEnvi alliance use national and European infrastructure designed for observing and providing data on the major components of the Earth's system (atmosphere, ocean, continental surfaces and solid earth) and the biosphere. This infrastructure is part of a national roadmap.

In 2010, the French Ministry of Higher Education and Research developed a new concept. Long-term observation and experimentation services for environmental research (SOEREs) seek to develop a national network of multi-organizational observation systems and disseminate data. AllEnvi is responsible for evaluating, organizing, accrediting and monitoring them. //

CLIMATE CHANGE: IPCC ASSESSMENTS

The Intergovernmental Panel on Climate Change (IPCC) was jointly established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), with the mandate to *"assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change".* The IPCC has produced climate change scenarios which world leaders can use as a basis for selecting public policies to reduce global warming.

OUTLOOK

21ST CENTURY FRANCE: HOTTER AND MORE EXTREME

The "Jouzel mission" reports provide regularly updated data on climate change in France, with the fourth report published in 2014. They aim to provide an analysis of climate change in France in the 21st century using changes in precipitation and temperature anomalies. Simulations were produced using two regional climate models implemented at the Météo-France and CNRS National Meteorological Research Centre (CNRM) and the CNRS / CEA / Paris Universities Institut Pierre-Simon Laplace (IPSL), in collaboration with the national competence center for industrial safety and environmental protection (INERIS). They are based on three of the four scenarios considered in the latest IPCC report (2013-2014).

> *"The idea is to provide an estimate of the trends for climate change in the coming century. The results given must not be interpreted as exact climate forecasts for specific geographical locations."*
> Jouzel report

What to expect

BY 2021-2050

↗ **An increase in average temperatures** of 0.6 to 1.3°C with respect to the baseline average calculated between 1976 and 2005. This rise would be greater in southeastern France in the summer, where increases could reach 1.5 to 2°C.

↗ **An increase in the number of heatwave days in summer,** 0 to 5 days across the whole of France, and 5 to 10 days in southeastern France.

↘ **A decrease in the number of unusually cold days in winter** 1 to 4 days over the whole of metropolitan France, and up to 6 days in the northeast of the country.

↗ **A slight increase in average precipitation** of 0 to 0.42mm/day on average, with significant uncertainty as to the geographical distribution of this change.

BY 2071-2100

↗ **A significant increase in average temperatures** in particular in southeastern France: this could be well over 5°C higher than the baseline average temperature in the summer.

↗ **A significant increase in the number of heatwave days in summer,** exceeding 20 days for the RCP8.5 scenario (RCP - Representative Concentration Pathway).

↘ **Decrease in extreme cold spells continues through to the end of the century.** Between 6 and 10 days fewer than the baseline in northeastern France.It should be more limited in the far south of the country.

↗ **Increase in winter precipitation.**

↗ **More extreme precipitation events.**

↗ **More droughts** across a large part of the south of the country, or extending across the whole country in one of the models.

OVERSEAS FRANCE

↗ **A temperature increase** of 0.7 to 3°C (or even 3.5°C) by 2100.

↘ **A decrease in average precipitation,** particularly in the dry season.

↗ **More intense cyclone activity at the beginning of the century** according to Volume 1, Chapters 11 and 14 of the fifth IPCC report, in the North-Atlantic basin, along with an increase in frequency of category 4 and 5 cyclones in the North-Atlantic and South-West Pacific basins.

↘ **By the end of the century, the overall frequency of tropical cyclones should diminish or stay the same.** The average rainfall and mean maximum windspeed associated with tropical cyclones will likely increase.

FOR FURTHER INFORMATION

CLIMATE IN FRANCE IN THE 21st CENTURY,
Report coordinated by Dr Jean Jouzel
> www.developpement-durable.gouv.fr/Volume-5-Changement-climatique-et.html

In 2010, the Ministry of Sustainable Development requested a consultation from the French community of climate sciences to produce a scientific assessment of the climate conditions in France in the 21st century. Dr Jean Jouzel was asked to head up this consultation, performed by researchers from CNRS-INSU/IPSL and LGGE, Météo-France, BRGM, CEA, CETMEF and CNES. All results are available on the DRIAS website
> http://www.drias-climat.fr/accompagnement/section/31

THE SIXTH NATIONAL COMMUNICATION OF FRANCE TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (October 2013) investments made by France in research and infrastructure.

THE VAST WEB OF RESEARCHERS

Observatories, measurement and experimentation sites, models, simulations...A vast and closely knit web stretches around the world and is growing stronger everyday thanks to French, European and worldwide cooperation between researchers. Its aim is to observe, measure, model and understand to better anticipate...An overview in pictures.

Observation is a key to understanding the causes and effects of climate change. A vast web stretches across the whole world, providing long-term observations from space or the ground, continents and their surface, the oceans and the atmosphere etc. All systems and tools available to scientists are being deployed to study soil, grasslands and forests, water in rivers, subsoil or glaciers etc. Balloons, aircraft, boats, buoys and submersibles are also used for observations in the air and seas to measure meteorological parameters, greenhouse gases and ocean acidification. Not forgetting space, where scientific satellites scan each corner of the earth. Whether on the local or global scale, observation is systematic and extends over decades. The data collected, gathered and used by researchers is shared at the international level and is available to all, including citizens, decision-makers, and economic and social stakeholders. This data improves our understanding of changes in the atmosphere, oceans and earth, so that climate and warming scenarios can be developed, with the aim of mitigating and adapting to changes. France is at the cutting edge, thanks to its network of research and observation infrastructure, represented in this graphic.

Space-based observations

Copernicus
A local and global monitoring system for the environment and safety.

> Watch the video (in French)
www.dailymotion.com/video/x232i30_space-live-4-les-sentinelles-de-la-terre_tech

CEOS constellations
The Committee on Earth Observation Satellites (CEOS) coordinates the Earth observation activities of space agencies, including CNES. It provides a coordinated response on data.

GCOS national and international data centers
All ground-based, airborne or ocean-based measurements are available to the scientific community thanks to Global Climate Observing System (GCOS) data centers.

Airborne atmospheric observation

The SAFIRE and IAGOS aircraft
Specialized aircraft fitted with instrumentation for detailed observation of atmospheric processes (SAFIRE) are supplemented by measurements performed on commercial airliners fitted with standard sensors (IAGOS).

The subsoil database for France
BRGM's subsoil database (BSS), has data from nearly 700,000 boreholes and underground works gathered over more than a century.

Earth observations

The SOERE rivers and forests networks
These networks measure variables such as river chemistry, precipitation, stream and river flow rates, soil moisture content, carbon sinks and flows, and production of wood for energy.

Peatland monitoring network
Peatland monitoring is organized around the measurement of carbon flows and in changes to permafrost.

GLACIOCLIM observations
The observation service studies the workings of glaciers in the Alps, the Andes and the Antarctic to provide a database.

Fluxnet programme
The aim of this European programme is to improve our understanding of the size, location and temporal variability of carbon sinks and sources.

The Mistral programme
A program based on seven environmental and climate themes for an integrated view of the Mediterranean system.

The AMMA-CATCH programme
African Monsoon Multidisciplinary Analysis - Coupling the Tropical Atmosphere and the Hydrological Cycle in West Africa.

The OVIDE programme
OVIDE monitors annual and ten-yearly ocean variability in the North Atlantic, with the goal of measuring currents and the thermohaline structure.

Ocean observations

Ships
Besides the permanent ships of the French ocean-going fleet, there are the ship-of-opportunity programme (SOOP) vessels (a fleet of 17 vessels with IRD and CNRS participation) and the vessels of the Voluntary Observing Ship (VOS) Programme (67 for France in 2012 with the WMO observation programme).

The Argo network
Argo France groups French activities associated with the international Argo network of free-drifting profiling floats that measure temperature and salinity as part of an oceanography project.

PIRATA buoys
Prediction and Research Moored Array in the Tropical Atlantic (PIRATA) is a network of buoys to study ocean-atmosphere interactions in the tropical Atlantic, coordinated by IRD, Météo-France and INSU.

Drifting buoys
Météo-France regularly deploys buoys to measure atmospheric pressure, sea surface temperature and wind speed, or sea temperature at depths of up to 300m.

GLOSS oceanography
French oceanography networks contribute to the Global Sea Level Observing System (GLOSS). They supply sea-level data useful for general ocean navigation and climate monitoring.

Ground-based atmospheric observations

ICOS stations
Integrated Carbon Observation System (ICOS) stations are found across Europe, analyzing greenhouse gases flows. RAMCES-ICOS measures atmospheric concentrations of greenhouse gases.

Météo-France networks
Météo-France has a special place in the systematic observation system. 554 stations are evenly distributed over the whole country.

Guam stations
Météo-France has 67 observation stations overseas.

GAW network
The Global Atmosphere Watch (GAW) network, managed by Météo-France, performs physical and chemical atmospheric measurements.

Crowdsourcing networks
Météo-France has put together a State Climatology Network (volunteer measurement stations and posts) using seafarers, the military, agronomists, farmers etc.

© Infographie : Nathalie Hourcade – Photos : F. Rhodes/CEA ; DR

THE CLIMATE SIMULATED AND ANALYSED

A quick overview of current knowledge on the climate and its changes, the current state of research, diagnostics, and observations via a few key results...

Climate research is highly varied and benefits from the findings in a number of disciplines working in conjunction. The French scientific community is actively working together. Various climate models simulate the exchanges between the atmosphere, ocean and land surfaces at different resolutions and use different approaches. In particular, a dedicated platform is used to model couplings between 'ocean and climate'. Here are a few key aspects of this work.

Modelling >>> To understand the workings of the climate system and predict changes, climate models are used to reproduce past variations prior to the impact of human activities, over geological time scales. Another approach consists on increasing the spatial resolution of the models to study the links between global climate and regional and local effects. Modelling can also simulate the future climate. Climate models are coupled with socio-economic models for adaptation to climate change.

CNRS | CEA | MÉTÉO FRANCE

Impact studies >>> A consortium of scientists has studied the impact of an overall temperature increase of 2°C in Europe, which is predicted for 2050 or even sooner! According to their analysis the continent would be significantly affected by the rise in temperature. We should expect more severe winters in northeastern Europe (with 20% higher precipitation) and hotter summers (with more severe droughts) around the Mediterranean.

CEA | CNRS | MÉTÉO FRANCE

Simulation >>> To predict these changes, researchers perform climate simulations including extreme events. Thanks to ice core research, one of their key discoveries has highlighted the link between CO_2 and temperature. These advances offer new simulations for the 21st century.

CEA | CNRS | MÉTÉO FRANCE

Innovation >>> Another innovative method for assessing the effect of warming on ecosystems is functional biogeography. This new science addresses a significant challenge, namely to understand the impact of climate change on the productivity of grasslands, carbon sequestration in forests and the sustainability of coral reefs.

CNRS | INRA //

ARGO: UNDERSTANDING MARINE CIRCULATION

With 3,000 drifting profiling floats across the world's oceans, the international ARGO programme measures ocean temperature and salinity in real time. Initial results include an estimate of heat storage by oceans, and insight into the formation of deep waters in polar regions in winter.

IFREMER | CNRS | SHOM | CNES | IRD | MÉTÉO FRANCE | IPEV

TRACKING CARBON

Visualizing CO_2 emissions and understanding the carbon cycle are crucial in the attempt to limit future CO_2 emissions to a maximum total of 1,200 billion metric tonnes. In 2013, the Global Carbon Project study showed that global CO_2 emissions are still increasing.

CEA | CNRS | INRA

CLIMATE DATA AT A CLICK

The 'Drias futures of climate' website aims to provide everyone with regionalized climate projections: number of unusually hot nights, number of days of frost or heatwaves etc.

MÉTÉO FRANCE | CNRS | CEA

AT A GLANCE

What about sulphate aerosols?

Observation of aerosols, clouds and trace gases in the atmosphere requires the specific equipment and measurements of the ATMO infrastructure. For example, taking into account the reduction in sulphate aerosols in models results in a greater increase in surface solar radiation in Europe and the Mediterranean, and a consequent increase in temperature.

CNRS | CEA | MÉTÉO FRANCE

Methane in ponds

Northern ponds, formed in summer by the surface melting of arctic permafrost, produce large quantities of methane, a powerful greenhouse gas. The smallest ponds are the most active producers!

CNRS

Ice core drilling

The Franco-Italian Concordia Research Station is one of the three permanent Antarctic stations. As part of the EPICA programme, deep ice core drilling provides insights into past climates going back 800,000 years.

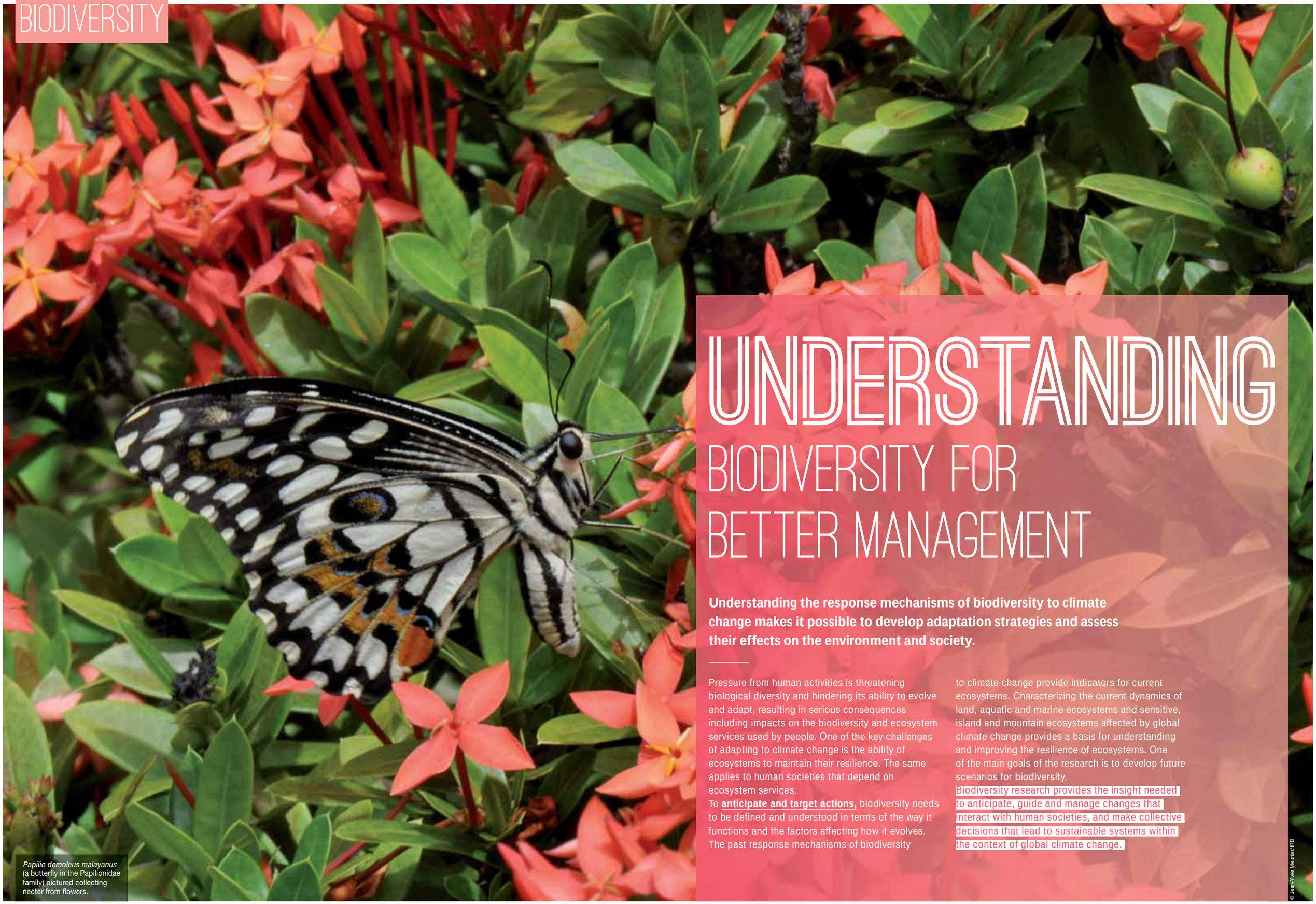
IPEV

Variability of water masses

The OVIDE project observes the currents and properties of water masses of the North Atlantic subpolar gyre. Ocean-based observations and modelling studies are performed in Greenland and Portugal.

IFREMER | CNRS

SUCCESS STORIES



Papilio demoleus malayanus (a butterfly in the Papilionidae family) pictured collecting nectar from flowers.

© Jean-Yves Meunier/IRD

UNDERSTANDING BIODIVERSITY FOR BETTER MANAGEMENT

Understanding the response mechanisms of biodiversity to climate change makes it possible to develop adaptation strategies and assess their effects on the environment and society.

Pressure from human activities is threatening biological diversity and hindering its ability to evolve and adapt, resulting in serious consequences including impacts on the biodiversity and ecosystem services used by people. One of the key challenges of adapting to climate change is the ability of ecosystems to maintain their resilience. The same applies to human societies that depend on ecosystem services.

To **anticipate and target actions,** biodiversity needs to be defined and understood in terms of the way it functions and the factors affecting how it evolves. The past response mechanisms of biodiversity to climate change provide indicators for current ecosystems. Characterizing the current dynamics of land, aquatic and marine ecosystems and sensitive, island and mountain ecosystems affected by global climate change provides a basis for understanding and improving the resilience of ecosystems. One of the main goals of the research is to develop future scenarios for biodiversity.

Biodiversity research provides the insight needed to anticipate, guide and manage changes that interact with human societies, and make collective decisions that lead to sustainable systems within the context of global climate change.

Corals are among the first animals to have populated the seas and oceans.

© DR

FOCUS

MAPPING CORAL REEFS

PREVENTING BLEACHING

WHAT

PROTECTING CORAL THREATENED BY GLOBAL WARMING

In the face of growing and alarming coral reef bleaching, researchers have mapped zones at risk according to rises in temperature.

CNRS

Coral bleaching is an extremely alarming phenomenon. It is a spectacular consequence of rising atmospheric temperatures and one of the main threats to coral reefs. In the 1980s, from the Atlantic Ocean and Caribbean Sea to the Pacific and Indian Oceans and the Arabian Peninsula and Red Sea, almost all the world's major coral regions began to be affected by this process, which has deteriorated since the 1990s, transforming numerous reefs.

Coral dies at temperatures over 30°C

Bleaching results from the loss of symbiotic algae living within the tissues of coral polyps. It is a stress phenomenon caused by a rise in ocean temperatures, generally above

30°C over periods of several weeks, which can cause the animal to die. By 2040, three-quarters of the world's coral reefs will be affected by coral bleaching at least once a year if nothing is done to stop the rise of atmospheric temperatures. The scientific community fears that all reefs will be affected by 2056.

To combat the predicted coral reef loss, French and American researchers have mapped out zones at risk using the latest climate forecasts produced by the Intergovernmental Panel on Climate Change (IPCC)

"This phenomenon occurs when the algae which feeds on the coral and gives it its colour is expelled when water temperatures rise above 30°C for two to four consecutive weeks," explains Serge Planes, co-author of a paper published on the topic in the journal *Nature Climate Change*. Depending on the species, bleaching causes coral to die in 15 to 60% of cases.

France is directly affected

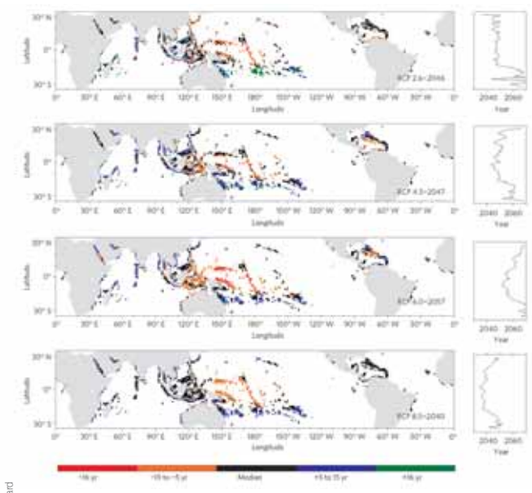
To model rising ocean temperatures and predict bleaching events, researchers used the most recent IPCC projections, which predict a 1 to 3°C rise in atmospheric temperatures by 2050.

Coral reefs off northwest Australia, the Philippines and Papua New Guinea are the most fragile and will be affected by annual bleaching events as early as 2025-2030. Less fragile zones include the Great Barrier Reef in Australia and French Polynesia, which are not likely to be affected before 2056. Nearly 4% of the world's surface is made up of coral reefs spread across its oceans. It should not be forgotten that France is directly affected.

> *"Reefs will change and tomorrow's dominant species will probably not be the same as today's."*

"It is difficult to predict how coral will adapt to the change in current equilibriums," explains Serge Planes. "Reefs will change and tomorrow's dominant species will probably not be the same as today's."

In fact, recent research predicts that the coral species most resistant to rising temperatures, with the highest growth rate and greatest longevity will fare the best. The marine ecosystem will therefore metamorphose and scientists are not sure whether it will be able to sustain the species that inhabit it. The mysteries of the seas and ocean depths remain… //



© Jeffrey Maynard

Four coral bleaching scenarios for a range of latitudes, with forecasts between 2040 and 2060 depending on rises in temperature. Maps showing years that reef locations start to experience bleaching conditions (colored scale).

FOR MORE INFORMATION

R. van Hooidonk, J.A. Maynard and S. Planes (2013), **TEMPORARY REFUGIA FOR CORAL REEFS IN A WARMING WORLD,** in *Nature Climate Change.* Vol. 3, pp. 508-511. [Online 24 February 2013]

> **criobe.pf/moorea**

AT A GLANCE

Land-use planning with Green and Blue Corridors

What can be done to facilitate species movement in their vital areas despite climate change? This is the goal of the Green and Blue Corridors built in different regions of France as part of the Grenelle de l'Environement *initiative and the strategy to create protected areas in France. 'Ecological continuities' were identified for open thermophilic environments and a number of research projects are underway to better understand the role of protected areas in the face of climate change.*

MNHN IRSTEA

Better understanding the adaptation of species to climate change

The various forms of global change affect how marine and continental ecosystems function. Researchers are working on the effects of exposing the larvae of certain fish (sole and sea bass) to warmer and less oxygenated environments. Once these larvae have grown, the adults show major physiological changes. The goal is to understand and predict how species adapt to warmer waters.

IFREMER

CLIMIT: protecting butterfly habitats

The European project CLimate change impacts on Insects and their MITigation *(CLIMIT) underlines the importance of creating and preserving grasslands for insects and particularly pollinators. Habitat heterogeneity makes it easier for species to adapt. These results have been used to make recommendations to policy makers and other stakeholders (managers, environmental agencies, etc.).*

MNHN

A major biological invasion in 2100?

Biological invasions (the arrival of a new plant or animal species in a place far from its natural habitat) are one of the greatest threats to biodiversity. The International Union for Conservation of Nature has even created a list of '100 of the World's Worst Invasive Alien Species', including the Asian hornet, the tiger mosquito, coypu and ragweed. One scientific team recently showed that climate change and land-use changes (deforestation, urban sprawl, agriculture, etc.) could potentially have devastating effects on the spatial distribution of these invasive species by 2100!

CNRS

Receding glaciers = 40% of aquatic fauna at risk

As thawing continues to increase globally, the diversity of mountain ecosystems is threatened. Researchers have found that if glaciers were to disappear, it would result in the extinction of 10 to 40% of aquatic fauna, depending on the region. Ecologists studied the biodiversity of glacier water streams in the Andes, at 3,500 to 5,000 metres. If the species living in these extreme environments were to disappear, some of the world's most unique ecosystems would be lost.

IRD

© Olivier Dangles/IRD

Antisana Nature Reserve, Ecuador, where numerous protected animal species, such as the famous Andean condor, are in danger of extinction.

Assessment of the traditional genetic resources of rice is a source of discovery for protecting its cultivation.

FEEDING THE WORLD

Climate change has a major effect on agricultural production. The global organization of food systems is affected. Solutions exist both for adapting consumption and using more responsible ways of producing more food. Agricultural greenhouse gases emissions can be limited through good practices.

Climate has a direct, immediate impact on harvests. Agriculture and climate are intrinsically linked. At a time of increasing temperatures, growing water scarcity and more frequent extreme weather events, food crises will increase if no concrete action is taken. **New diversified models of consumption** could provide answers. Society as a whole is affected. The primary goal is to **rethink global agriculture** to meet the **food needs** of the entire planet. As for consumption, gaining a better understanding of price volatility on world markets, improving harvest forecasting in sensitive areas, reducing waste and spoilage, anticipating stocks, managing shortages, and maintaining access to land are among the paths to be explored. The nutritional aspects of food and ecosystem protection are also important. The scenarios of the Agrimonde foresight study examining global food and farming systems in the years leading up to 2050 looked at the impact of a 30% reduction in meat consumption and a reduction in waste and spoilage. Consumer behaviour appeared as a key factor.

The second goal is to **rethink production methods, adapt to biotic and abiotic stresses resulting from climate change, reduce greenhouse gases emissions,** and contribute to carbon sequestration. For instance, to achieve this, research work quantifies the uncertainties on future crop and grassland yields. Other studies examine the genetic adaptation of cattle in the Mediterranean region. Measures are proposed to reduce the greenhouse gases emissions of French agriculture. This includes reducing fertilizer use, selecting different varieties, farming with nitrogen-free fertilizers and reducing ruminant methane emissions. Similarly, international research is striving to design and assess practices that are more productive, reduce greenhouse gases emissions and contribute to carbon sequestration.

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FOCUS

BETTER CROP MONITORING TO AVERT FOOD CRISES

Farmers in sorghum fields participating in a breeding programme (central Burkina Faso).

WHAT

IMPROVING FOOD SECURITY AND DEVELOPING EARLY WARNING SYSTEMS

Since the 1980s, researchers have been developing a computer model to simulate and monitor annual crops, in particular to estimate the impact of a climate scenario and predict crop yields. The latest version of the SARRA-H model has now been applied to West African countries. It could serve as an early warning system to avert food crises.

CIRAD

Assessing sowing dates, monitoring crops and water availability step by step, and predicting potential yields are some of the benefits of the SARRA-H system (version H of the system for regional analysis of agro-climatological risks), a unique crop monitoring model that several teams of French scientists have been developing over the last 30 years. Launched in the 1980s, this model is especially adapted to the global issues of climate change and food security, and seems to have proven its effectiveness. Furthermore, its latest version has been available in three languages (French, English and Portuguese) since 2014. This wide-ranging work has led to various applications on the subject in France's partner countries.

> *"Estimating and forecasting biomass and potential yield to ultimately manage crops better to avert food crises that global warming could make worse."*

Application in 17 West African countries

SARRA-H has recently integrated new improvements, specific to the issues of an early warning system for West Africa in order to avert food crises. On the basis of this model, teams of researchers can provide hydric monitoring, the state of crops and yield forecasts.

Since 2013, AGRHYMET, in partnership with the French teams and with the support of the World Meteorological Organization (WMO), has offered a series of training workshops on the new version of SARRA-H. No fewer than 17 countries in West Africa are involved. In Brazil, the new version of SARRA-H has now been applied to the Tracking Oil Spills & Coastal Awareness (TOSCA) project, in association with direct sowing and soybean crops. It has also been used in the context of the European project Stimulating Innovation for Global Monitoring of Agriculture and its impact on the environment (SIGMA). The Brazilian government used the model to implement public policy on credit management for farmers. In place for 20 years, this policy has doubled production and generated considerable savings for the country.

Analyzing the impact of climate on cereal growth

SARRA-H is a powerful tool for simulating crop growth, and the upgraded version of the SARRA software suite can be used to estimate the impact of a climate scenario on annual crops. SARRA-H is more specifically adapted to analyzing the impact of climate on the growth of dry cereals, such as millet, sorghum, corn and rainfed rice, cultivated in West Africa, along with soybeans. To achieve this, various processes (soil water balance, potential and actual evaporation and transpiration, phenology, potential assimilation and assimilation under water stress, maintenance respiration, and biomass distribution) are used to simulate potential crop yield, giving priority to simple robust approaches.

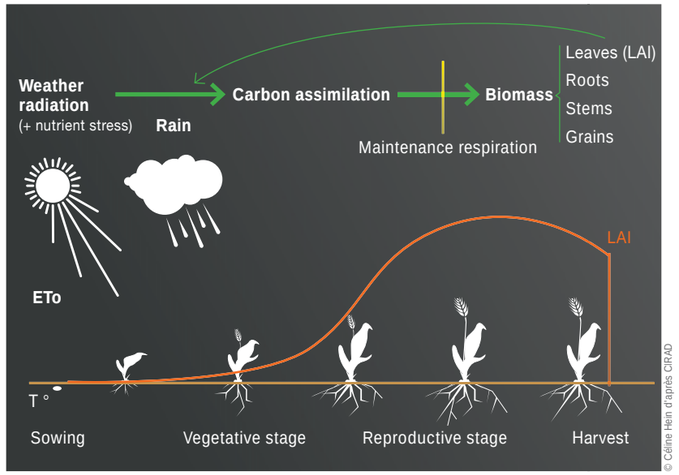
Having demonstrated its strong performance in this area, the software has been calibrated using a series of local, modern varieties of millet, sorghum and corn. Tests are conducted in controlled environments. To assess the predictive quality of the model, agronomic monitoring was performed many times over several years with subsistence farmers. The sites selected, in Niger, Senegal, Mali and Burkina Faso, are impacted by both agricultural practices and climate.

Finally, a series of scenarios representing agricultural practices was produced. Different crop varieties were also highlighted. For example, specific studies were conducted on local cultivars of sorghums and millets, which are notable for their strong sensitivity to photoperiod, and led to a module integrated into the model.

On the technical level, teams explain that SARRA-H is "a modular deterministic model of crop growth from the plot to regional scale." It integrates three major processes into a single daily cycle: water balance, carbon balance (biomass) and vegetative phenology.

Objectives: estimating and forecasting biomass and potential yield

Thanks to their network of partners, in the North and especially in the South, scientific teams representing ...



© Céline Hein d'après CIRAD

The model integrates three major processes within a single daily cycle: water balance, carbon balance (biomass) and phenology.

CLIMATE (constraint)	PLOT (soil)	AGRICULTURAL PRACTICES (strategies)
▪ Evapotranspiration ▪ Temperature ▪ Solar radiation ▪ Rainfall Daily time step	▪ Type (clayey, sandy etc.) ▪ Maximum depth ▪ Surface reservoir depth	▪ Species, Variety ▪ Sowing date/ strategy ▪ Sowing density ▪ Irrigation ▪ Fertility level

The model operates using a simple set of input data that allows for multiple simulation scenarios as shown in the table above.

© Patrick Duguié/CIRAD

Using SARRA-H, farmers in Burkina Faso can simulate their sorghum yields.

... disciplines such as meteorology, climatology, remote sensing and computer modelling have succeeded in developing a model for the tropical environment, with efficient parametrization, process conceptualization, and an environment and interfaces adapted to users. The goal is to estimate and predict biomass and potential yield, with the hope of better crop management, and thereby averting a potential food crisis exacerbated by global warming.

Sowing strategies

There are many applications in this context. Beyond food security, the model follows the state of crops during the season and predicts potential yields to provide an early warning system. SARRA-H can also check if farming strategies are well adapted for the local environment. For example, sowing strategies are a major challenge (estimated risks related to early or late sowing, simulation of sowing dates or seedling death). Finally, the model enables work to be carried out on strategies for subsistence versus cash-crop farming and optimization of water resources.

All these benefits make SARRA-H an important tool for improving food security and developing early warning systems. //

FOR FURTHER INFORMATION
> http://sarra-h.teledetection.fr
> http://sarra-h.teledetection.fr/Doc/Manuel_SARRA-H_en_cours.pdf

Watch the video (in French)
SARRA-H: monitoring crops to better anticipate risks

FOCUS

ADAPTING VINES AND WINE

WHAT

CLIMATE CHANGE THREATENS FRENCH WINE PRODUCTION

LACCAVE project researchers are studying various solutions to literally save French vineyards in the face of global warming. In particular, they are exploring the possibility of relocating vines...

INRA

Earlier grape harvests, increased water stress on vines, less acidic wine with higher alcohol content and new flavour profiles... These are the initial consequences of climate change on viticulture and French wine. The situation is urgent! Today's vineyards could be facing serious difficulties, and some could even disappear as a result of global warming. This could happen within just a few decades. These effects are going to increase, with various positive or negative consequences for different vineyards. For this reason, a team of French researchers, working together on the Long term impacts and Adaptations to Climate ChAnge in Viticulture and Enology project (LACCAVE, 2012-2015), are studying strategies for adapting French vineyards to climate change.

The project includes 23 research laboratories across France. Their aims are to assess the effects of climate change on vines and wine, explore adaptation strategies, and propose scenarios for French wine-making regions. The approach is multi-disciplinary because it combines research from climatology, genetics, ecophysiology, agronomy, oenology, economics and sociology etc. Multiple solutions are therefore being brought to light.

Relocating vines

The first of these solutions considers relocating vines, based on possible innovations, from the choice of grape varieties to wine-making techniques. It also explores adaptation to changes in consumer preferences and changes in wine-making legislation

Analysis is being performed at various levels: plants, plots, vineyards, regions and sectors. Special attention is being focused on the regional level, where climate has different impacts. This is the level at which adaptation strategies can be coordinated. One of the original hypotheses of the LACCAVE project is that vineyard adaptation will also depend on the ability of stakeholders to build relevant relationships with technicians and researchers.

Scientists are therefore exploring possibilities for replanting vines in regions with lower temperatures or at higher altitudes. According to Herve Quénol and Benjamin Bois, who are both part of the LACCAVE project and specialists in small-scale climate studies, "there is as much climate variability within a single wine-making region, even a small one, as between two different wine-making regions".

1.8 to 4°C higher temperatures in a century

Scientists are warning that "the warming predicted for mid-century will not be without risks for vines and wine". By the end of the 21st century, various simulations predict that temperature could rise by 1.8 to 4°C! Climate predictions are controversial. In general, precipitation is forecast to slightly increase. The only exception to the rule would be temperate regions during the summer. In any case, all researchers agree on one thing: that extreme weather events will be more common. And this will affect vineyards.

> *"Vineyard adaptation will also depend on the ability of stakeholders to build relevant relationships with technicians and researchers."*

© JeanWeber/INRA

Champagne vineyard in Cerseuil (northeastern France).

Grapes ripened 18 days earlier

In reality, the impact of climate change on wine production is not something new. In just 30 years, grapes are harvested two to three weeks earlier depending on the region – and this is continuing! Agronomists estimate that Riesling and Gewurztraminer varieties will ripen 18 days earlier by the middle of the 21st century.

This would have an impact on the quality of the grapes, which would become sweeter and less acidic. The wine would have a stronger alcohol content with completely different flavours. In addition, there will be new threats such as diseases and other pests, induced by climate disruption. In this context, vineyards appear to be a priority research focus for scientists seeking to understand the smallest changes in ecosystems.

Wineries as laboratories

French research is now studying adaptation strategies for the French vineyards of the future. Researchers ...

© Christophe Maître/INRA

Installation of sensors in a Bordeaux vineyard to study the physical mechanisms that govern transfers between plant cover and the atmosphere.

... are therefore testing new varieties that ripen later and are more resistant to drought and heat on experimental vineyards in Alsace, Aquitaine and Languedoc-Roussillon. They are assessing new practices, including irrigation, and reducing pruning and leaf removal of vines to better protect grapes from the sun.

Wineries are their laboratories. They test different techniques to reduce the alcohol content or adjust the pH of grape juice etc. Finally, they survey wine producers to better anticipate the reactions of professionals in the face of climate change and necessary adaptations.

Where do consumers stand in this? They have not been left out. Their taste for new wines and their willingness to purchase are analyzed in detail. This should be expected given that France is the top wine consuming country on the planet and that wine is France's second-ranked export sector, according to industry magazine *Vin & Société.* //

FOR FURTHER INFORMATION
> www1.montpellier.inra.fr/laccave

AT A GLANCE

The coffee genome has finally been sequenced...

An international consortium coordinated by a French team has just published the first reference sequence for the coffee plant genome, a plant of primary economic importance. Coffea canephora, *better known as robusta, was chosen for its diploid genome (2 x 11 chromosomes), while* Coffea arabica, *the other cultivated species, is a tetraploid hybrid (4 x 11 chromosomes) of robusta and* Coffea eugenioides, *and therefore more complex to sequence. By combining several sequencing technologies, the researchers deciphered the 710 million base pairs of its DNA and identified over 25,000 genes. This identification of agronomic interest should facilitate the selection or creation of varieties that are more resistant to environmental constraints and pests (such as insects, fungi and viruses).*

CEA CNRS CIRAD IRD

© P. Latron/LookatSciences/CEA

Installation of a flow cell containing prepared samples into a high-throughput sequencer (Illumina), in the Genoscope sequencer room.

...and so has the rapeseed genome!

The same international consortium has just published the reference sequence for the rapeseed genome. This is a powerful tool for improving varieties. Rapeseed has only recently begun being cultivated on a large scale and has strong potential for genetic improvement. This reference sequence will make it easier to identify genes of agronomic interest in order to improve oil content and composition, resistance to pathogens, frost tolerance, yield and efficiency of using nitrates in soil.

CEA CNRS INRA UNIVERSITÉ D'ÉVRY

Rice is not afraid of heat!

By measuring rice spikelet temperatures, researchers are studying the mechanisms developed by the plant so that it can flower despite the heat. This knowledge is integrated into models, meaning that growing practices can be adjusted and new varieties bred.

CIRAD

© Julie Debru/CIRAD

Cottonseed harvested by hand is sorted. Carpels are separated from the cottonseed (white) to improve the quality, and therefore selling price.

Cotton drought resistance

A French team working with Brazilian researchers is studying the drought resistance of 250 varieties of cotton plants by growing them in rhizotrons so that root development can be monitored.

CIRAD

© Pierre Marraccini/CIRAD

CIRAD – EMBRAPA ATP project 'Phenotypic Plasticity in Response to Water Constraints in Coffee Plants Growing Under Field Conditions'

Coffee plants adapting to multiple stresses

In Latin America, French researchers are analyzing coffee-plant adaptation to combinations of stress (such as drought, diseases and nematode attacks), with a view to offering new varieties and cropping methods suitable for agroforestry.

CIRAD

LCA to better assess environmental impacts on production

Life cycle analysis (LCA) assesses the environmental impacts throughout a production system, from raw material extraction to a product's end of life. The ACV-Cirad© database uses this approach and covers the entire life cycle of a product: from raw material extraction to production, consumption and waste, for products from developing countries (citrus fruit, cotton, tomatoes, palm oil, coffee, rice, cassava, jatropha and beef).

CIRAD

Atlantic bluefin tuna: a fragile giant in recovery

Atlantic bluefin tuna is a mysterious species that fascinates scientists and constitutes an important field of study. As a shared resource with high market value, it is fished by around 20 countries.

French researchers studying the ecology of bluefin tuna have worked on the history of its overfishing between 1990 and 2000, and produced management models for stock recovery, from 2007 to 2022, for a species that is particularly sensitive to the thermal environment.

IFREMER

Gaining a better understanding of the impact of climate change with rubber plantations

In Thailand, French researchers and their partners are measuring water and carbon exchanges between rubber plantations and the atmosphere using flux observation towers. Understanding the behaviour of these plantations will help test various climate change scenarios.

CIRAD

Rural African populations in tough conditions

To understand how Sub-Saharan African populations perceive and adapt to climate variability, sociologists, anthropologists, demographers, climatologists, economists, geographers and agronomists performed field surveys, in Senegal, Mali, Niger and Benin, over four years as part of the Environmental and Social Changes in Africa: Past, present and futurE (ESCAPE) project. The results confirm significant warming in West Africa over the last century, re-greening in the Sahel region since the late 1990s and an increase in extreme weather events. While rural populations have so far succeeded in adapting, projections show that agriculture will be severely constrained if warming reaches +2°C. These conditions could jeopardize the ability of local populations to adapt.

IRD

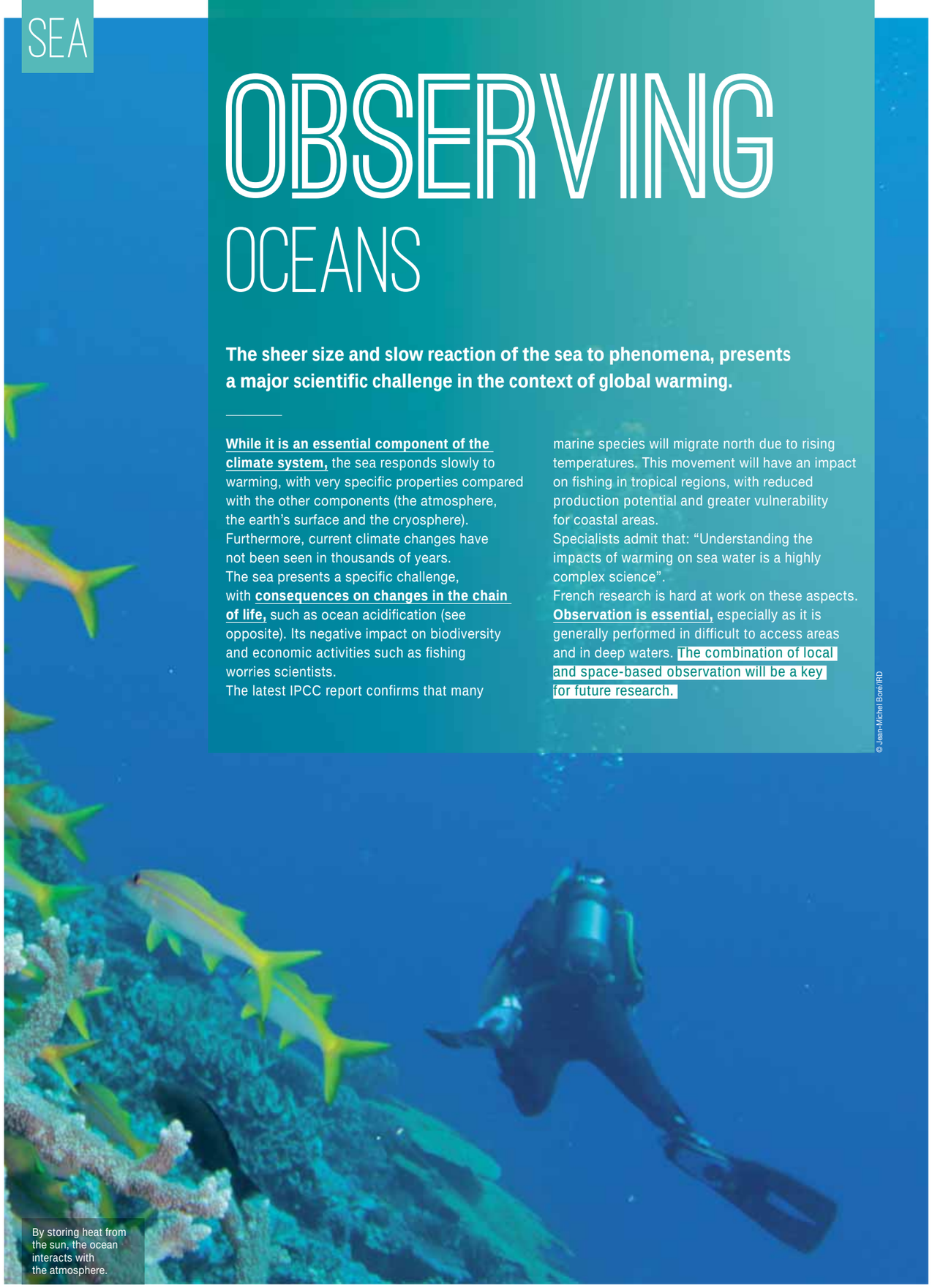
© Guy Trébuil/CIRAD

Terraced rice paddies after harvest in a village near Guilin, in southeast China.

OBSERVING OCEANS

The sheer size and slow reaction of the sea to phenomena, presents a major scientific challenge in the context of global warming.

While it is an essential component of the climate system, the sea responds slowly to warming, with very specific properties compared with the other components (the atmosphere, the earth's surface and the cryosphere). Furthermore, current climate changes have not been seen in thousands of years.
The sea presents a specific challenge, with **consequences on changes in the chain of life,** such as ocean acidification (see opposite). Its negative impact on biodiversity and economic activities such as fishing worries scientists.
The latest IPCC report confirms that many marine species will migrate north due to rising temperatures. This movement will have an impact on fishing in tropical regions, with reduced production potential and greater vulnerability for coastal areas.
Specialists admit that: "Understanding the impacts of warming on sea water is a highly complex science".
French research is hard at work on these aspects. **Observation is essential,** especially as it is generally performed in difficult to access areas and in deep waters. The combination of local and space-based observation will be a key for future research.



© Jean-Michel Boré/IRD

By storing heat from the sun, the ocean interacts with the atmosphere.

FOCUS

ALARMING OCEAN ACIDIFICATION

FOR FURTHER INFORMATION
Villefranche-sur-Mer Oceanology Observatory:
> www.obs-vlfr.fr

Ocean pH levels have dropped by 30% since the start of the industrial revolution. This phenomenon disturbs the entire marine ecosystem and could have devastating effects on many marine species.

IFREMER CNRS

Ocean acidification is one of the little-known consequences of human activities. Scientists are now beginning to understand its effects better. Acidification is directly associated with the increase in the quantity of carbon dioxide in water, and is induced by excessive greenhouse gases emissions, leading to a gradual drop in ocean pH levels. Mean ocean acidity is set to triple by 2100!

The threat is significant because acidification "will impact organisms that construct their shells or skeletons with calcium carbonate, such as coral and molluscs, leading to disruptions in polar and coral ecosystems," say researchers, following recent work by French scientists.

The marine food chain at risk

New research has shown that the increase in ocean acidity "amplifies the harmful effect of warming on coral growth". Like molluscs and some phytoplankton species, coral produces a calcium-carbonate skeleton, but excessive ocean acidity slows down this production.

Affected coral and pteropods (gastropods living in the water column) will no longer be able to feed or shelter the various organisms that depend on them. This could lead to increased mortality of marine species, with consequences for atolls, whose very existence relies on coral reefs. At the other end of the food chain, little data is currently available. However, a few studies show that the sensory system and thus the behaviour of certain fish species could be affected by a drop in pH levels.

As this is a recent field of research, real uncertainties exist surrounding the consequences of this phenomenon. No numerical data is available for the moment, as current ocean acidification is a rapid process and unprecedented in the history of our planet. //

© S. COMEAU/CNRS Photothèque/UPMC/LOV

Pteropods play a key role in the Arctic food chain and are highly sensitive to ocean acidification.

AT A GLANCE

Are Marine Protected Areas still effective?

The Mediterranean has over a hundred Marine Protected Areas (MPA) to protect marine biodiversity. Population connectivity, in particular provided by larval dispersal due to currents, is essential to the effectiveness of these populations. For example, the dusky grouper is a notable Mediterranean species that is heavily fished and whose survival depends on Marine Protected Areas. Researchers have shown that Mediterranean MPAs are far from providing a true connected network. The average distance between MPAs is 1,032km, while the average dispersal distance of dusky grouper larvae is only 120km, which means that many local populations are totally isolated. The phenomenon is even more disturbing given that climate change (based on an assumption of a 2.8°C temperature increase by the end of the 21st century) will affect the degree of connectivity of Mediterranean fish populations by reducing larval dispersal distance by 10%.

CNRS FRB IRD

Phytoplankton: adapting fishing strategies

For the first time, researchers have assessed the ability of numerical models to predict long-term changes in a biological parameter at the bottom of the marine food chain: the primary production of phytoplankton. These natural variations could be predicted several years in advance in the equatorial Pacific. This paves the way for potential rational fishing strategies that cover several years.

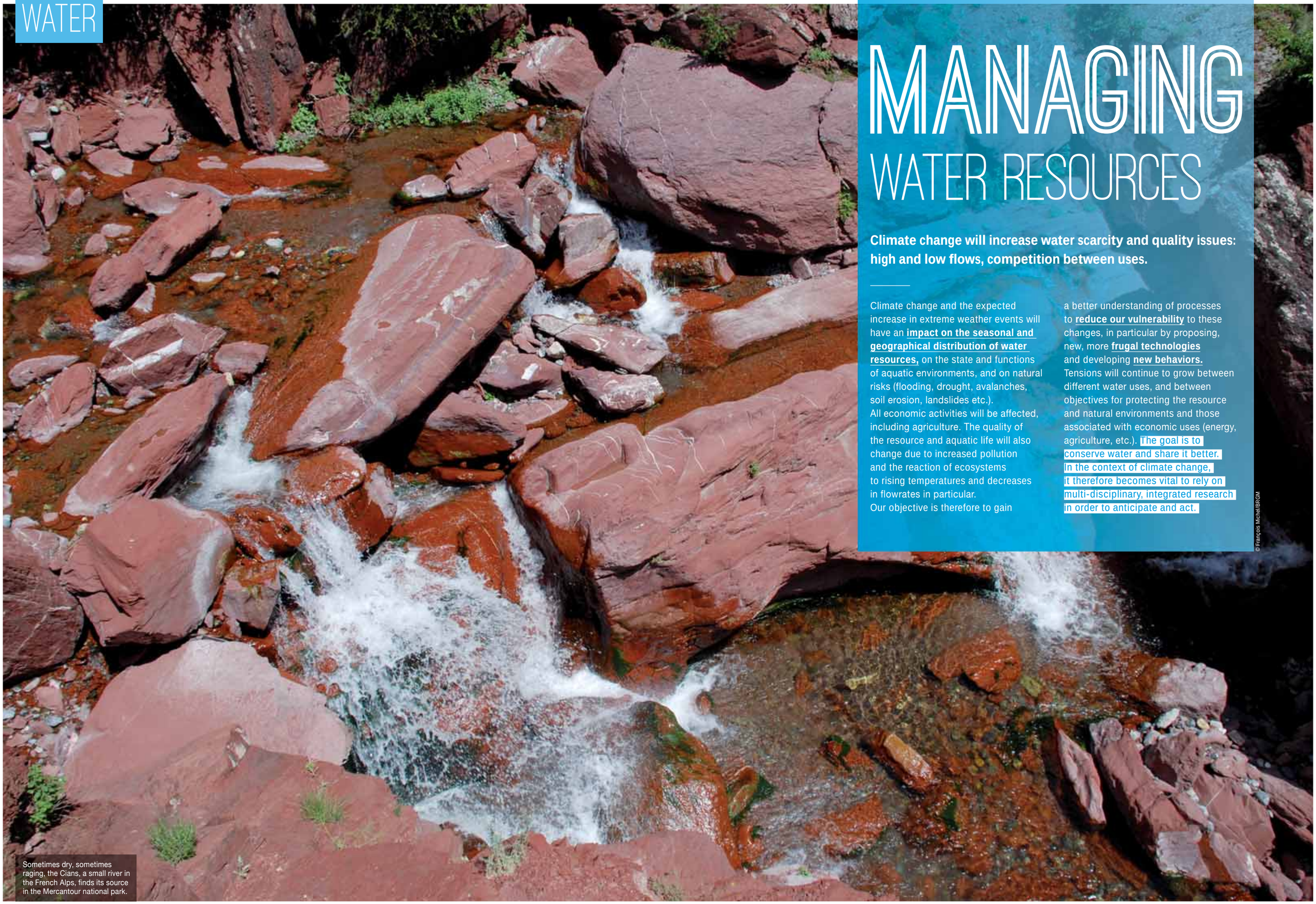
MÉTÉO FRANCE CEA CNRS

Acidification reduces the size of marine shellfish

An international study coordinated by a French team, in association with Italian researchers, demonstrated that the size reduction observed in certain marine organisms during past mass-extinction crises could be the consequence of ocean acidification. This reduction would have allowed them to survive in the presence of high CO_2 levels, a phenomenon that could recur in the future as a result of climate change.

IRD

Watch a video about the OUTPACE oceanography mission.



MANAGING WATER RESOURCES

Climate change will increase water scarcity and quality issues: high and low flows, competition between uses.

Climate change and the expected increase in extreme weather events will have an **impact on the seasonal and geographical distribution of water resources,** on the state and functions of aquatic environments, and on natural risks (flooding, drought, avalanches, soil erosion, landslides etc.).
All economic activities will be affected, including agriculture. The quality of the resource and aquatic life will also change due to increased pollution and the reaction of ecosystems to rising temperatures and decreases in flowrates in particular.
Our objective is therefore to gain a better understanding of processes to **reduce our vulnerability** to these changes, in particular by proposing, new, more **frugal technologies** and developing **new behaviors.**
Tensions will continue to grow between different water uses, and between objectives for protecting the resource and natural environments and those associated with economic uses (energy, agriculture, etc.). The goal is to conserve water and share it better. In the context of climate change, it therefore becomes vital to rely on multi-disciplinary, integrated research in order to anticipate and act.

© François Michel/BRGM

Sometimes dry, sometimes raging, the Cians, a small river in the French Alps, finds its source in the Mercantour national park.

© L. Emperaire/IRD

One bank of the Rio Negro in the Amazon.

FOCUS

GROUNDWATER SEEN FROM SPACE

WHAT

IMPROVING OUR UNDERSTANDING OF AQUIFERS AND THEIR IMPACT ON CLIMATE

Almost all fresh water - 96% of it - is beneath our feet. However, these invisible reservoirs are difficult to study. Researchers have developed a method to map aquifers ...from space. This is being applied to the Amazon rainforest ecosystem.

IRD

Launched in 2002, ENVISAT is the largest European Earth observation satellite.

© ESA

How do we map the water beneath our feet? The answer is from space! While groundwater represents 96% of fresh water on the planet, aquifers are by definition underground and therefore have been very difficult for scientists to study. The specific geographical location of certain aquifers also makes it difficult to observe them using traditional methods.

A major advance has been made for wet regions like the Amazon rainforest, where French researchers, with Brazilian partners, have succeeded in developing a new method for measuring groundwater tables.

Using images from the European ENVIronment SATellite (ENVISAT), scientists have produced the first maps of the Amazon aquifers beneath the largest rivers in the world, the Amazon and the Rio Negro. This Earth observation satellite was launched by the European Space Agency in 2002, to continuously measure environmental parameters related to the atmosphere, the ocean, land masses and ice at various scales.

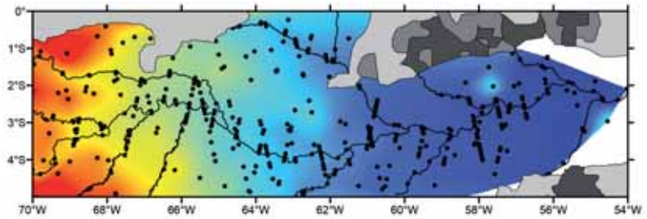
The maps produced show groundwater tables during the low-water periods from 2003 to 2008. They also explain how the aquifer responded to droughts, such as the one that occurred in 2005. The aim is to better characterize its role in the Amazon climate and ecosystem.

MIGHTY AMAZON

The Amazonian forest, the world's most extensive tropical rainforest, has an average temperature of 26°C all year round. This vast reservoir of biodiversity is also home to the world's greatest river, the Amazon, which is some 6,300 km long from its source in Peru to the Atlantic Ocean into which it flows. During the rainy season, between December and May, it can attain a width of 20 km wide and carry almost 20% of the planet's fresh water.

Although its size and geographical location make it hard to study, Amazon groundwater plays a vital role in this rich alluvial ecosystem. It provides rivers, lakes, surface waters and flood plains with an abundant supply of water during the drier seasons, meaning that plants suffer less water stress.

LOW-WATER GROUNDWATER TABLE FOR THE CENTRAL AMAZONIAN CORRIDOR



This map shows the mean groundwater table during the driest periods of the year between 2003 and 2008.

Key

Main Rivers

Virtual stations based on space altimetry

Level of the groundwater table above the geoid (m)

Values

High: 75

Low: 0

© Pfeffer, J., F. Seyler, M.-P. Bonnet, S. Calmant, F. Frappart, F. Papa, R. C. D. Paiva, F. Satgé, and J. S. D. Silva (2014), Geophys. Res. Lett., 41, 1981–1987, doi:10.1002/2013GL059134.

Mapping from space

Mapping from space is a unique method already used on oceans and now applied to the Amazon. The research team developed a method for studying aquifers using satellite altimetry measurements. This technique has only been used for a few years, to observe continental surface water. Several years of work were needed to calibrate and validate data that had been collected. Over 500 rivers, lakes and flooded areas in the Amazon Basin were thus scrutinized to specifically determine altitudes and level variations.

No fewer than 491 measurement stations

By using the concepts of interaction between underground and surface water and altimetry data gathered by the ENVISAT satellite, scientists were "able to assess groundwater table topography during low-water periods in the alluvial plain of the central Amazon".

These measurements required no less than 491 altimetry stations positioned on the water's surface, providing unprecedented coverage to match the vastness of the Amazon Basin! As a result, groundwater table maps have been developed with a resolution of 50 to 100km.

Aquifers finally revealed

Amazon groundwater now has its first maps! This feat was performed using this observation network, the largest ever deployed on this scale. Researchers found that during the dry season, surface reservoirs are at the same level as the aquifer that feeds them. The altimetry measurements thus obtained provided direct observations of groundwater levels. Precise mapping of the groundwater table at low-water level, i.e. at its lowest level during the year, from 2003 to 2008, revealed consistency between the measurements obtained by the scientists and direct measurements of water depth performed in wells.

> *"There is a significant 'memory effect' in the aquifer that could have a significant impact on climate."*

The water table can remember!

The 2005 drought had a significant impact on most of the study area, because, according to scientific observations, the low-water level suddenly dropped. Over the months, this level rose little by little from North to South. It only recovered its mean value between 2007 and 2008. This revealed to researchers a significant 'memory effect' in the aquifer. It could even have a significant impact on climate. The consequences of unusually low water levels are well known: a reduction in evapotranspiration, reduced air humidity and an ultimate decrease in rainfall.

Satellite mapping of aquifers has proved to be an essential source of data. This method is a major advance for hydrology studies and reveals the spatial and temporal structure of Amazonian groundwater for the first time. This major project provides a better understanding of large-scale underground hydrological processes. This is essential environmental data as it directly concerns the water cycle, the carbon cycle and maintenance of biodiversity in the Amazon. Groundwater has lost its mystery! //

FOR FURTHER INFORMATION

J. Pfeffer, F. Seyler, M.-P. Bonnet, S. Calmant, F. Frappart, F. Papa, R. C. D. Paiva, F. Satgé, and J. S. D. Silva. 2014. **LOW-WATER MAPS OF THE GROUNDWATER TABLE IN THE CENTRAL AMAZON BY SATELLITE ALTIMETRY,** in *Geophysical Research Letters.*

FOCUS

IRRIGATION: NEW TECHNOLOGIES FOR MORE EFFECTIVE AND OPTIMIZED USE

WHAT

MITIGATING WATER SHORTAGES IN AGRICULTURE

Irrigation of food crops and green spaces consumes large quantities of water. To reduce its impact, researchers and engineers are working to develop new technologies, in particular a system for treating and reusing wastewater. Here is an overview.

IRSTEA

There are many innovative irrigation techniques and practices to reduce pressure on water resources. French scientific and R&D teams are working to improve existing technologies and develop new more economical systems.

For example, subsurface drip irrigation (SDI) is a well-known technique that has already been subject to numerous innovations. SDI is an attractive solution for most countries faced with a shortage of 'blue gold', due to its efficacy. As an increasing number of French regions face water restrictions, it is becoming a viable option for irrigating large-scale crops.

© IRSTEA

Close-up of a subsurface drip irrigation system.

Subsurface drip irrigation

Subsurface drip irrigation first appeared in the United States over 20 years ago and is suitable for potatoes, fruit trees, wheat and vines. It consists of burying localized irrigation lines over small surface areas, which then release small quantities of water to plants. Its main drawback is that tubing has been found to be vulnerable to clogging and root intrusion. The appearance of new, more effective materials have enabled it to be applied to large-scale crops, such as corn, under certain conditions.

For large-scale crops, specialists recommend the use of irrigation lines fitted with drippers 30 to 40cm apart and buried 30cm deep, i.e. below ploughing depth. Each dripper delivers water at an even nominal flowrate. Anti-siphon and anti-root systems prevent soil particle and root intrusion.

Scientists stress one of the advantages of drip irrigation compared with classic spray irrigation: "With no wind effects and with effective automatic regulation, SDI uses 20% less water (under the climatic conditions of Montpellier), i.e. one or two irrigation sprinkler uses. However, during a dry spring, wind erosion can be a problem and require supplementary spraying."

> "Wastewater recycling: a promising system in the context of climate change."

Wastewater for farming and roadways

Another avenue being explored concerns the recycling of wastewater to irrigate crops. This is the idea of the REUSE project for treated wastewater reuse. France has recently adopted suitable legislation that should pave the way for a promising system to mitigate water shortages in agriculture in the context of climate change.

Implemented as part of the New process for Optimizing Wastewater Reuse from Mauguio to the Mediterranean Area (NOWMMA) project, running from 2012 to 2015, REUSE is based on suitable treatment for the distribution of wastewater to plants. This R&D project led to the development of a pilot scheme tested in Mauguio, in the Camargue, which was then extended to the entire Mediterranean Basin.

© B. Molle/IRSTEA

Assessing aerosol drift using a spray system and water with a coloring agent added to simulate wastewater.

The purpose of the experimental development is to offer a technologically innovative wastewater reuse network, with a system and maintenance practices suitable for this type of use. It has undergone environmental and economic assessments and, must above all, be socially acceptable.

The pilot scheme must answer the following questions: how are the risks inherent in wastewater reuse managed? Are there health risks for people or plants? What are the technological risks?

NOWMMA is not only for the irrigation of green spaces and crops, but also, to a lesser extent, for road and vehicle cleaning. The pilot project should lead to commercial products for the deployment of a modular system that can be exported throughout the Mediterranean basin. //

FOR FURTHER INFORMATION
RÉUTILISATION DES EAUX USÉES TRAITÉES POUR L'IRRIGATION DES CULTURES, L'ARROSAGE DES ESPACES VERTS PAR ASPERSION ET LE LAVAGE DES VOIRIES *(WASTEWATER REUSE FOR CROP IRRIGATION, WATERING GREEN SPACES AND ROAD CLEANING)*
– ANSES Opinion. Collective consultation report. March 2012. Édition scientifique.

See the video *Advantages and drawbacks of subsurface drip irrigation*

AT A GLANCE

R²D²: The Durance River in 2050

The R²D² 2050 (2011-2014) research project is a foresight study on the Durance basin water resource towards 2050, involving scientists and local stakeholders. The modelling system produced provides a set of projections for the resource itself and for water demand for various uses (drinking water conveyance, irrigation, tourism and energy).
A tool has been designed to simulate management of major hydraulic structures (including the Serre-Ponçon dam) and allocation of the water stored in these structures. The results obtained for different scenarios for global change indicate greater constraints on water management and reservoirs by 2050.

IRSTEA

S. Thebault/IRSTEA

The Durance River.

WAG: roleplaying game

"Wat A Game" (WAG) is a roleplaying game kit focusing on water management and governance that has been used over 50 times in operational and educational contexts in Africa, Europe and Asia. Its goal is to teach and assist water and catchment basin management by inviting participants to discuss various resource-availability scenarios. This project proposes solutions for adaptation.

IRSTEA

Less rainfall in Montpellier

Nine climate forecasts were performed to assess the impact of climate change on water resources in the Lez karst system, which supplies drinking water to 340,000 residents in Montpellier and the surrounding area. These forecasts predict a 1.5°C to 2.3°C (±1°C) increase in monthly mean temperatures, depending on the time of year. As for rain, a 10% drop in annual total rainfall could occur by 2046-65 in comparison with the baseline situation (1971-2000).

BRGM

Reduced water quantities in Martinique

What will be the impact of climate change on Martinique's surface water and groundwater resources by 2081-2100? Simulation has been performed using a global hydrological model and on the basis of climate forecasts. The results are that available water quantities would reduce significantly in the dry season. Increasing shortages are to be expected, in particular in the center of Martinique where the rivers appear particularly vulnerable to this phenomenon.

BRGM

What is the expected drought situation for the 21st century?

Launched in March 2008, the CLIMSEC project has characterized the impact of climate change on water resources, with a special focus on soil moisture. Using baseline data for rainfall, soil moisture and river flowrates, the various forecasts predict the appearance of unusually long and extensive drought phenomena with respect to current norms, from the middle of the 21st century.

MÉTÉO FRANCE

South India in 2045

An Indian team from the Indo-French Centre for Groundwater Research and French remote sensing specialists performed a study which reveals that climate change, as forecast for 2045, will have varied effects on the availability of groundwater within a single catchment basin in India.
It shows the importance of taking local characteristics into account (aquifer, infrastructure and practices) to assess the impact of climate change on agricultural practices.

BRGM

Determining HIV protease resistance to antiretroviral therapies.

PREVENTING EMERGING INFECTIOUS DISEASES

Dangerous links exist between climate and emerging infectious diseases. Global changes risk directly or indirectly affecting human health via emerging or re-emerging infectious diseases.

While it is difficult to establish a direct link between climate variations and global changes in infectious diseases, **new illnesses are appearing,** caused by previously unknown bacterial or viral agents or by changes to known agents under the effect of climate variations. These are emerging or re-emerging infectious diseases, such as leishmaniasis, West Nile virus, etc. According to the World Health Organization (WHO), infectious diseases cause a third of deaths worldwide, mainly in developing countries.

Several parameters could be responsible for the increased spread of pathogens and their hosts. Climate change modifies the temperature and humidity conditions of natural environments, and the distribution areas, abundance, behaviour, biological cycles and life history characteristics of these pathogens and their hosts. **These effects are still poorly explained.** Research needs to develop an understanding of long-term spatial and temporal changes in these phenomena.

© E. Perrin/CNRS Photothèque

FOCUS

AVIAN MALARIA PREDICTING INFECTION

WHAT

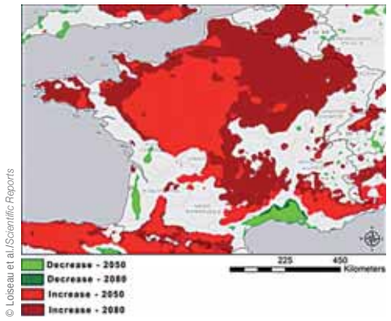
AVIAN MALARIA COULD AFFECT BRITTANY AND NORTHERN FRANCE

The map of the projected spread of avian malaria into the regions where it is currently rare, suggests that France will not be spared. What role does climate change play in the emergence of this infection risk?

CNRS IRD

Chikungunya, dengue fever and malaria are infectious diseases that have been little known in France until now, but which are gradually appearing in hotspots in the southern half of the country. According to scientists, the influence of climate change on the emergence of these infectious diseases is clear. Temperature and rainfall levels can affect the speed of pathogen development, and the abundance and survival of the invertebrates that transmit them. This is clearly the case with the mosquitoes that carry malaria and dengue fever. It is therefore possible that warming will promote the transmission of certain pathogens and increase their range of distribution.

AVIAN MALARIA IN BRITTANY AND NORTHERN FRANCE



© Loiseau et al./*Scientific Reports*

On this map, areas where the prevalence of avian malaria will reduce by at least 1% are shown in green; areas where the prevalence of the disease will increase by at least 10% are shown in red. This clearly shows an increase in Brittany and northern France.

> *"The disease will spread to regions that have been relatively spared so far."*

Using field sampling, an international study involving several French researchers, produced a model that aims to predict the way in which global warming will affect avian malaria in France. The results, published in *Scientific Reports*, show that within a few decades rising temperatures will promote the spread of the disease into regions where it is currently seldom encountered, such as Brittany and the northern part of the country.

1,750 birds examined in 24 locations

It is difficult to estimate the spread of infectious diseases because many health measures are implemented to limit their emergence and expansion. In the face of the increased risk of contracting avian malaria predicted by various climate scenarios, the disease is actually declining in the areas where it is endemic, and has been for a few decades.

The international study in question therefore freed itself from socio-economic factors by focusing only on pathogens in wild fauna, in this case the avian malaria parasite in house sparrows. The pathogen is a protozoa, of the genus *Plasmodium*, similar to that which causes human malaria.

As infected mosquitoes pass the illness to birds, the network of amateur bird ringers from the French Research Centre on Biology of Bird Populations (CRBPO) examined 1,750 birds in 24 locations in France.

To attribute the variability of avian malaria prevalence (proportion of birds infected) to environmental factors, researchers focused on temperature, precipitation and altitude data for each of the sites studied.

Predicted prevalence of the disease in 2050 and 2080

Brittany, Normandy and Nord-Pas-de-Calais are currently little affected by avian malaria, but by 2050 they will also be hit by this disease. The authors of the study in question analyzed several climate factors, such as daily temperature variations, to produce a model to predict the prevalence of the infection in 2050 and 2080. Climate change accounts for 83% of the prevalence variability observed. This model also indicates that the disease will increase in areas where the parasite is currently transmitted. //

FOR FURTHER INFORMATION

C. Loiseau, R. J. Harrigan, C. Bichet, R. Julliard, S. Garnier, A. Z. Lendvai, O. Chastel & G. Sorci. 2013. **PREDICTIONS OF AVIAN PLASMODIUM EXPANSION UNDER CLIMATE CHANGE**, in *Scientific Reports*.

An extract from the film *Malaria, the serial killer* (in French)

Aedes aegypti drinking blood. This mosquito is the vector for yellow fever and dengue fever.

© N. Rabiola/IRD

FOCUS

INFECTIOUS DISEASES: WHAT ARE THE FUTURE RISKS?

WHAT

ANTICIPATING PROPAGATION

Infectious diseases are a major public health issue and the subject of multi-disciplinary research, in particular in Africa and the South Pacific. The impact of climate change is now being assessed to anticipate propagation risks and protect populations.

CIRAD IRD MÉTÉO FRANCE CPU

Rift Valley fever, leptospirosis, dengue fever, chikungunya, Zika fever and Ross River fever are all examples of infectious diseases with animal vectors, of which the best known is the mosquito. A single bite can have terrible consequences for a person in Africa or Australia. The environmental component is therefore clear, as mosquitoes need a favourable climate to develop. This is where scientific research comes in, to understand how these illnesses spread and identify the determining factors.

Rift Valley fever is a major viral illness of ruminants in sub-Saharan Africa. It is transmitted by the bite of an infected mosquito and by direct contact. French researchers are attempting to develop models to predict the risk of the disease being introduced into North Africa and Europe. The aim is to better target the areas to be monitored. Through their work, they have gained a better understanding of the role of rain in the dynamics of temporary ponds. These are the main habitats where the vector mosquitoes lay their eggs. Simulations have revealed that episodes of Rift Valley fever, reported in Senegal and southern Mauritania, occur in years when the two main vector species are present at the same time in high numbers. In the Arabian peninsula, large-scale importation of small ruminants is the cause, while in Madagascar, cattle trading is the origin of virus circulation.

For Pacific Island Countries and Territories (PICTs), mosquito-borne viruses and leptospirosis are the cause of major public health concerns. Many scientists are directly or indirectly interested in this health issue. Whether specializing in infectious diseases, ecology, zoology, or public health, all rely on modelling the effects of climate change to assess the spread of infection risks to the populations of these island countries and territories. Collaboration is essential for deploying tools to anticipate emerging health issues. //

AT A GLANCE

Anticipating climate-related outbreaks of dengue fever

A scientific study performed in New Caledonia has demonstrated the key role that climate plays in epidemic dynamics. French researchers and their New Caledonian counterparts analyzed epidemiological and climate data, gathered in Nouméa over 40 years. They revealed the correlation between specific climate conditions and the appearance of dengue fever outbreaks. This work has produced explanatory and predictive statistical models for viral episodes.
While the New Caledonian public health authorities have already integrated these tools into their decision-making strategies, a similar approach is being developed in other South Pacific countries, with a new collaborative regional program.

IRD

War on ticks, insects and rodents!

What is the effect of environmental change on the emergence of vector-borne diseases (carried by mosquitoes, ticks etc.)? As part of the EDENext project (Biology and control of vector-borne infections in Europe), French researchers have organized vector-specific working groups.
Ticks: what is the transmission risk for new pathogens or the Crimean–Congo hemorrhagic fever virus?
mosquitoes, such as Aedes albopictus, *and the risk of transmission of the dengue fever and chikungunya viruses, or* Culex *species and the risk of transmission of West Nile virus.*
Phlebotominae (sand flies): what is the transmission risk for the leishmaniasis pathogen, or the viruses responsible for various kinds of encephalitis in several Mediterranean countries?
Biting midges: Culicoïdes *and the risk of transmission of viruses responsible for animal diseases that threaten the Mediterranean and Europe.*
Rodents and insectivores, are vectors for hantaviruses, orthopoxviruses and the lymphocytic choriomeningitis virus in Europe.

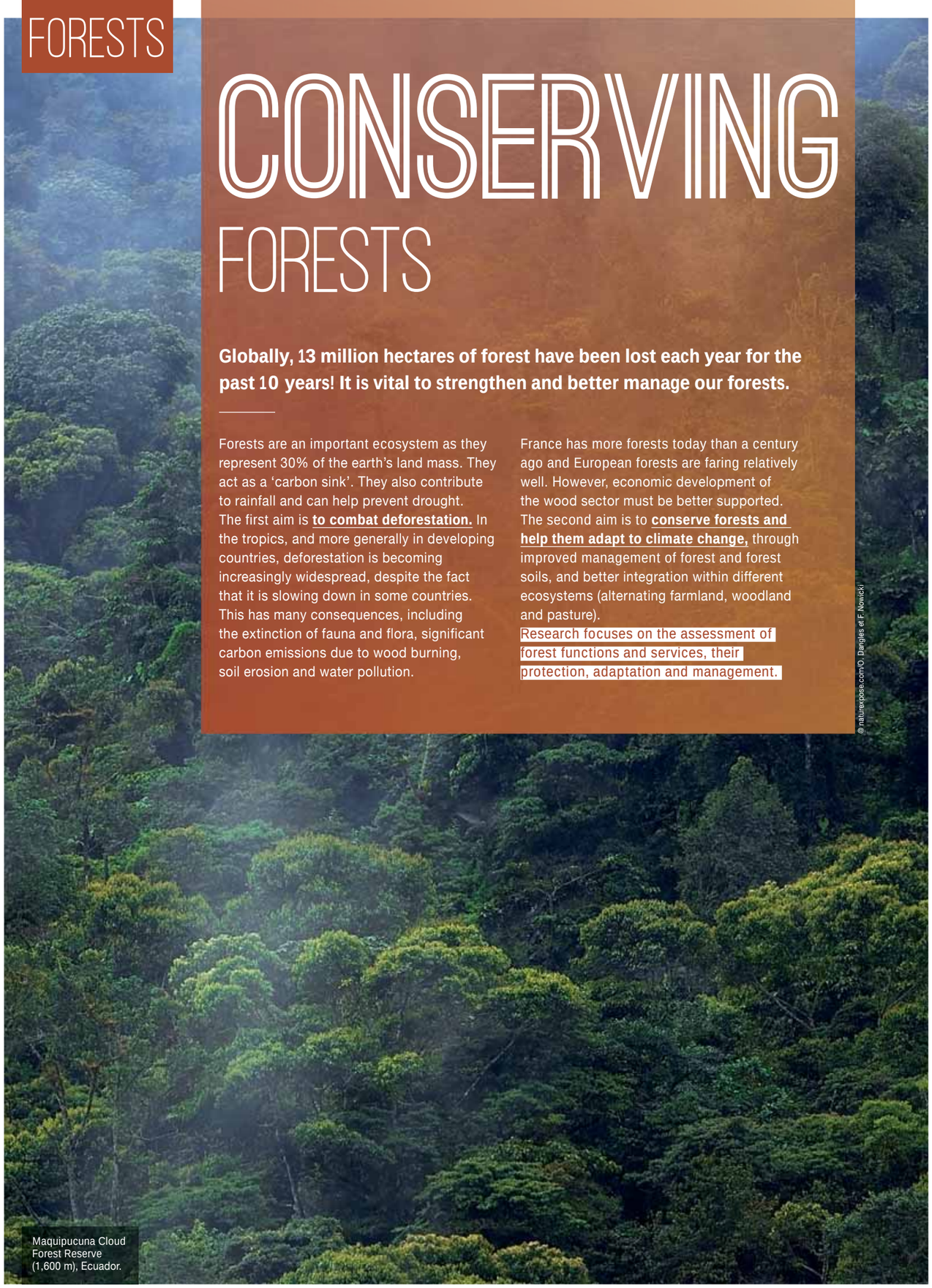
CIRAD IRD

CONSERVING FORESTS

Globally, 13 million hectares of forest have been lost each year for the past 10 years! It is vital to strengthen and better manage our forests.

Forests are an important ecosystem as they represent 30% of the earth's land mass. They act as a 'carbon sink'. They also contribute to rainfall and can help prevent drought. The first aim is **to combat deforestation.** In the tropics, and more generally in developing countries, deforestation is becoming increasingly widespread, despite the fact that it is slowing down in some countries. This has many consequences, including the extinction of fauna and flora, significant carbon emissions due to wood burning, soil erosion and water pollution.

France has more forests today than a century ago and European forests are faring relatively well. However, economic development of the wood sector must be better supported. The second aim is to **conserve forests and help them adapt to climate change,** through improved management of forest and forest soils, and better integration within different ecosystems (alternating farmland, woodland and pasture).
Research focuses on the assessment of forest functions and services, their protection, adaptation and management.



© naturexpose.com/O. Dangles et F. Nowicki

Maquipucuna Cloud Forest Reserve (1,600 m), Ecuador.

FOCUS

THE FUTURE OF TROPICAL RAINFORESTS

90% of French Guiana is covered by Amazonian rainforest and the country is home to over 1,500 tree species. Although deforestation is only a minor issue, this exceptional natural heritage is threatened by climate change.

CIRAD CNRS AGROPARISTECH INRA UNIVERSITY OF THE FRENCH WEST INDIES AND GUIANA ONF

French Guiana's tropical rainforests host a wealth of exceptional biodiversity, but are threatened, not by deforestation, fragmentation or deterioration of the landscape, but by severe climate events such as repeated droughts and ever-rising temperatures. The Amazonian rainforest is vital to overall planetary equilibrium, providing water and climate regulation, carbon sequestration and wood production. French researchers launched the CLIMFOR project to better understand current threats. Its aim is to explore the consequences of climate change on four 'ecosystem services' in the region: plant diversity, functional diversity, carbon sequestration and wood resources. Some 95% of the population live in northern French Guiana, where there is no baseline map for ecosystem services. Thanks to new modelling techniques, CLIMFOR used meteorological data, forest inventories and functional traits to make projections according to various climate scenarios.

Early results show a significant 'water stress' effect, particularly for wood regeneration, with negative consequences on the growth of various commercial species. Researchers also explain that, "trees tend to renew their leaves at the end of the dry season by drawing on their reserves for optimal photosynthetic efficiency at the start of the rainy season". This seasonal pattern of the forest may be threatened by a more intense dry season.

Mapping areas in need of protection

Scientists have successfully produced so-called 'irreplaceability' maps that identify priority protection areas. The results suggest that carbon stores in the forests of French Guiana are sufficiently uniform for biodiversity to be the major goal across all protection areas. These results have proven useful to direct forest management practices. //

© Daniel Sabatier/IRD

Low-lying Cochlospermum forest on granite outcrops (Monts d'Arawa, Southern French Guiana). This forest glade illustrates the diversity of flora and their relationships within a rare and fragile environment.

AT A GLANCE

Fire, fire!

Forest fires. The FUME project (Forest Fires Under Climate, Social and Economic Changes) has created tools to better manage future forest fires. In a context of climate, social and economic change, FUME seeks to improve forest fire fighting and prevention policies. Risk zone maps have been drawn up for Europe and the Mediterranean basin, on a regional and overall scale, according to climate change and changes to land use and human activities. These tools and long-term models are extremely useful for policy makers for the implementation of land-use planning that takes into account the risk of fire.

Resilience. The second aim of the FUME project is to increase resilience to future threats. One way of achieving this is by promoting mixed stands, which are better suited to facing extreme climate conditions. Researchers also recommend planting techniques that use the cover of existing vegetation (nurse plants) to encourage the growth of more diverse vegetation. Experimental nurse plant plots have been created in Saint-Mitre-les-Remparts. ***Should forest be destroyed by fire, a decision-making tool known as Postfire-DSS has*** *been developed to propose concrete restoration actions depending on the species, local climate and extent of damage.*

IRSTEA

To what extent can forests adapt?

The FORADAPT project was launched in 2013 and will run until 2016 with the aim of assessing climate change adaptation strategies for forests. It seeks to broaden and compile current knowledge of forest adaptation mechanisms (phenotypic plasticity, migration, genetic variation, community rearrangement and forest management) and improve existing databases. It also involves identifying adaptation strategies to ensure the long-term future of the ecosystem services provided by forests. For this, FORADAPT has created ***the first network of scientists in this field*** *where members pool knowledge and data.*

IRSTEA INRA

CHANGING OUR ENERGY NEEDS

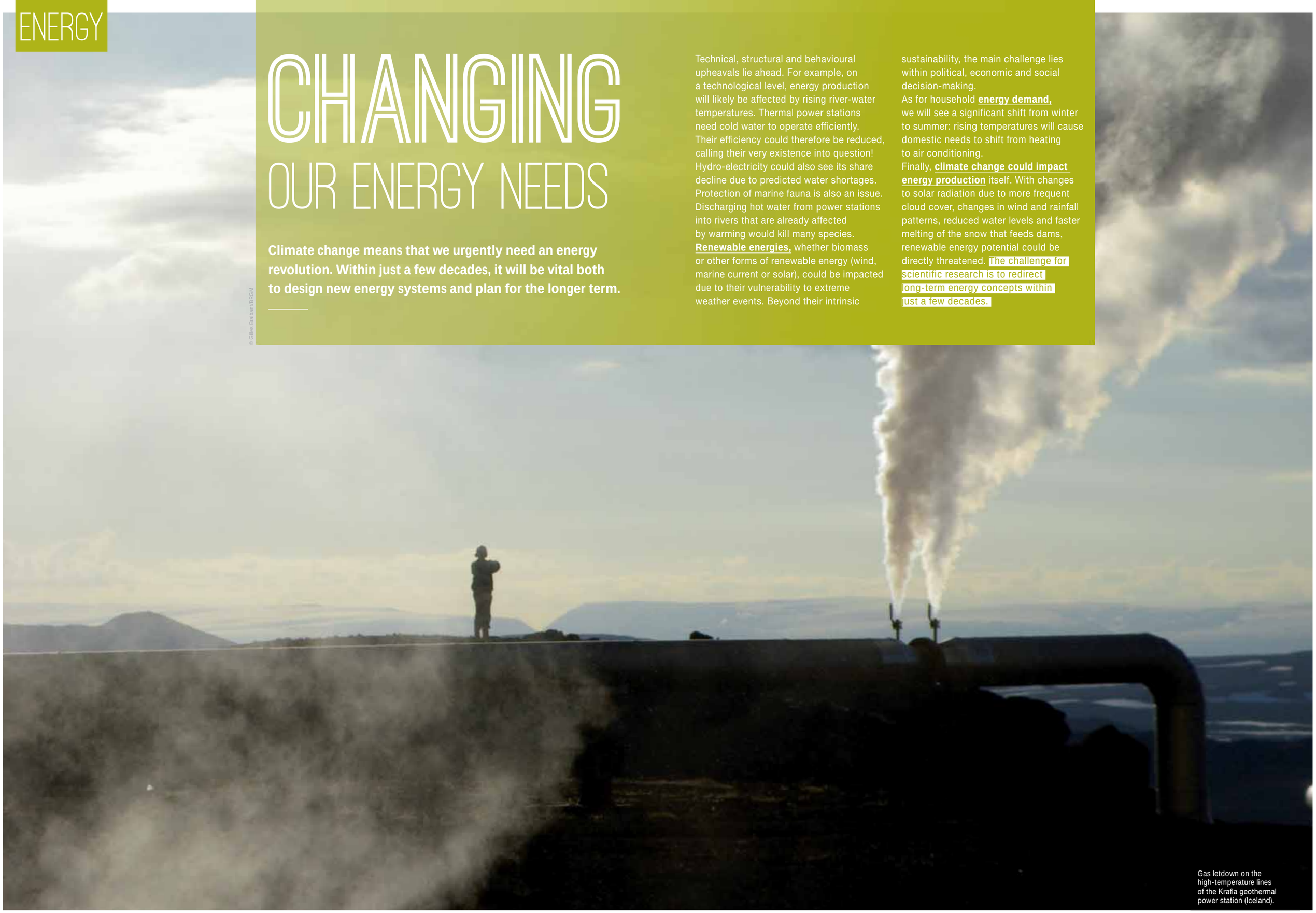
Climate change means that we urgently need an energy revolution. Within just a few decades, it will be vital both to design new energy systems and plan for the longer term.

Technical, structural and behavioural upheavals lie ahead. For example, on a technological level, energy production will likely be affected by rising river-water temperatures. Thermal power stations need cold water to operate efficiently. Their efficiency could therefore be reduced, calling their very existence into question! Hydro-electricity could also see its share decline due to predicted water shortages. Protection of marine fauna is also an issue. Discharging hot water from power stations into rivers that are already affected by warming would kill many species. **Renewable energies,** whether biomass or other forms of renewable energy (wind, marine current or solar), could be impacted due to their vulnerability to extreme weather events. Beyond their intrinsic sustainability, the main challenge lies within political, economic and social decision-making.

As for household **energy demand,** we will see a significant shift from winter to summer: rising temperatures will cause domestic needs to shift from heating to air conditioning.

Finally, **climate change could impact energy production** itself. With changes to solar radiation due to more frequent cloud cover, changes in wind and rainfall patterns, reduced water levels and faster melting of the snow that feeds dams, renewable energy potential could be directly threatened. The challenge for scientific research is to redirect long-term energy concepts within just a few decades.

© Gilles Brabant/BRGM



Gas letdown on the high-temperature lines of the Krafla geothermal power station (Iceland).

During a journey, GECO shows how to improve driving behaviour.

© IFP ENERGIES NOUVELLES

FOCUS

ECO-DRIVING IS POSSIBLE!

A WEB 2.0 APPLICATION

PRINCIPLE: GECO guides drivers to improve their urban driving behaviour.

After recording the characteristics of the vehicle and the number of passengers, this new driving companion uses existing smartphone functions, such as GPS, to calculate in real time the ideal driving behaviour to adopt, based on the journey. It then compares this to the drivers' actual behaviour, and displays their score and the improvements to be adopted, along with practical advice. Energy performance is displayed, as is journey history, assessments and points for improvement

> *"Coming soon: new energy efficiency, safety and maintenance services for the connected car."*

FOR FURTHER INFORMATION
GECO can be downloaded for free via
> www.geco-drive.fr

WHAT

A SMARTPHONE DRIVING APP THAT CAN REDUCE FUEL CONSUMPTION BY 10 TO 15%

After having taken care of our health, our shopping and our fitness, our smartphones can now help us adopt green driving! The GECO app is an innovative, user-friendly Web 2.0 system than can reduce a driver's fuel consumption.

IFP ENERGIES NOUVELLES

Reducing carbon emissions and fuel consumption are goals shared by all, and everyone has a daily part to play. Driving is a way in which nearly every citizen can contribute. How can we use our cars more efficiently? Researchers have developed an innovative mobile app. GECO enables drivers to adopt more thrifty driving behaviour, and enables businesses to assess and contribute to reducing their ecological footprint via this energy tracker. In short, this is called eco-driving. The purpose is to reduce consumption without necessarily reducing average speed. The key point is a 10 to 15% fuel saving.

An innovative system

Researchers developed new algorithms and integrated them into the GECO app. This is an innovative scientific approach in that it succeeds in quantifying driving analysis. It thereby provides more accurate and detailed information. At the heart of the app are online optimization algorithms based on automation research expertise and developed as part of the VME project for energy in urban mobility. "This project first studied the issues associated with eco-driving, or more precisely fuel-efficient driving. It formalized the situation mathematically, using a model for vehicle energy consumption, and offers resolution methods that are available online," explain its engineers.

→ Flexibility

Contrary to popular opinion, reducing speed is not the only way to reduce fuel consumption and carbon emissions. GECO proves this because it acts on several driving parameters, without obliging the motorist to slow down. The app analyzes overall data for the journey and gives driving advice. It uses a detailed assessment of various journeys made by drivers to analyze their behaviour in more detail, develop points for improvement and monitor progress.

→ User-friendliness

Like every self-respecting app, GECO offers a user-friendly interface. Results are delivered instantly as graphics to be read at a glance!

Destination: the connected car

This new eco-driving system is a testament to the successful integration of information and communication technologies into cars: "The connection of vehicles to their environment (infrastructure and other vehicles) will make other functions possible. Eco-driving as currently implemented in GECO is only a first step to smarter connected cars," explain the engineers involved in the app.

Available in the iPhone App Store and Google Play, the GECO app is free. Studies are already underway to offer new software services for connected vehicles, for energy efficiency, safety, prevention and maintenance, etc. //

WHAT IS ECO-DRIVING?

While technical progress has led to more fuel-efficient cars, motorists can still influence their energy consumption. Maintaining a stable speed, anticipating traffic, changing gears to keep the revs low, maintaining the vehicle, avoiding unnecessary loads, driving more slowly and shutting off the engine when it is not needed are all eco-driving practices that save fuel. Eco-driving can also save drivers a lot of money and have a positive impact on road safety!

FOCUS

ORGANIC WASTE
A NEW BIO-RESOURCE

© C. Bittouni/IRSTEA

Household waste storage centre operating in bio-reactor mode, in Cuves (northeastern France).

WHAT

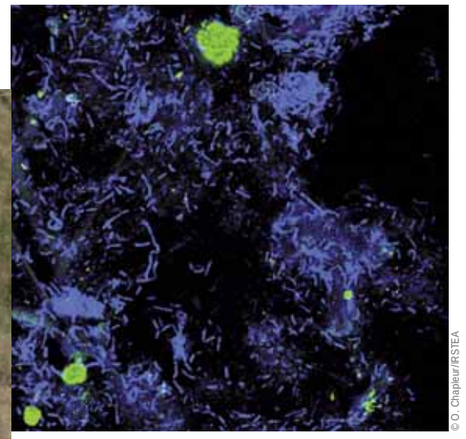
MICROBES FUELED BY WASTE

Organic waste is an innovative, green and widely available bio-resource, and a major asset for future energy. The Biorare project, led by French scientists and funded by the government's Investing in the Future programme, uses biomass in the place of petroleum products. This reuse system is a serious option for the future of the planet.

IRSTEA CNRS INRA

In the fuels and petrochemicals sector, finding an alternative to fossil energies was for a long time in the realm of the impossible. But never say never! Researchers have developed an innovative project in this field, known as Biorare, which is based on the electrosynthesis of platform molecules. This research programme produces simple organic molecules by the microbial electrosynthesis of organic waste. This is a good way of reusing the 30 million metric tonnes of household waste produced each year in France.

Use of this bio-resource is a major step forward on many levels. Firstly, it allows significant savings in fossil resources, reserves of which are depleting every day. Secondly, the raw material, which is organic waste (household, food, green and agricultural waste), is inexpensive and widely available, because we all produce it in large quantities. Finally, this resource is renewable and will ultimately replace petroleum products, which are subject to international markets and harmful for the environment.



© O. Chapleur/IRSTEA

Microorganisms marked by fluorescent probes and observed under a confocal laser scanning microscope.

Breakthrough technology

Biorare won the 2011 call for 'Biotechnology and bio-resources' projects of the French Investing in the Future programme, launched using a 'National Loan'. It is based on a technological breakthrough: microbial electrosynthesis, which is the production of organic compounds by the reduction of carbon dioxide, performed by microorganisms fixed to the cathode of an electrochemical cell. This process uses a bioelectrochemical system (BES).

Use of this technique for processing organic waste has the advantage of combining waste treatment by oxidation with the production of useful molecules. This can be physically separated from the synthesis of chemicals of biological origin. It is therefore easier to recover the biomolecules and there is a lower risk of contamination.

Thanks to the National Loan and collaboration with major industry players, who are convinced by the possibilities of the project, technical, environmental, economic and acceptability specifications can be drawn up, with a view to preparing for future industrial roll-out. //

FOR FURTHER INFORMATION
A. Bridier, E. Desmond-Le Quemener, L. Rouillac, C. Madigou, E. Blanchet, B. Erable, A. Bergel, A. Carmona, E. Trably, N. Bernet, L. Aissani, L. Giard, L. Renvoise, A. Bize, L. Mazeas, T. Bouchez. 2014. COMBINATION OF BIOANODE AND BIOCATHODE FOR THE CONVERSION OF WASTES INTO BIOCOMMODITIES USING MICROBIAL ELECTROSYNTHESIS.

AT A GLANCE

Slurries for heat transfer

What fluids will be used for heat transfer in future refrigeration plants? Research is advancing on various water-based, salt-based or glycol-based 'slurry' type fluids (ice slurries, hydrate slurries and paraffin slurries) for heat transfer without environmental impact. These processes are currently fitted to refrigeration plants with very convincing results, including energy savings, absence of toxic fluids, etc.

IRSTEA

© Madeleine Carouee

Phase-change material for cold storage.

Inventing the refrigeration of the future

The food cold chain is responsible for 8% of global energy consumption and 2.5% of greenhouse gases emissions. The 26 partners of the European FRISBEE project are therefore investigating refrigeration of the future, with successful developments such as magnetic refrigeration that uses no fluid coolant, or the use of phase-change materials that reduce energy consumption.

IRSTEA

© Joomla

Food refrigeration: a health issue with high potential for energy savings.

© A. Giac/IRSTEA

A methanation plant in Germany.

Methanation on farms

Methanation on farms produces sustainable, renewable energy which limits the use of fossil fuels that emit greenhouse gases. Research on mix optimization is currently seeking to achieve collective methanation which uses all the products of an area. In collaboration with a small business, researchers have developed a method for implementing a system across an entire geographical area, while minimizing the environmental impacts. This type of system is already being organized in Brittany.

IRSTEA

Reusing CO_2 to reduce emissions

The VASCO project dedicated to reusing and storing CO_2 is studying ways to reuse the CO_2 emitted by industrial activity in the Fos-sur-Mer basin, in order to reduce greenhouse gases emissions into the atmosphere by reuse of purified CO_2 in industry, acid gas injection into oil fields to optimize their yields, or geological disposal in the saline aquifers of the PACA region. Following initial research (2011-2012), a new promising avenue opened up: CO_2 absorption via microalgae photosynthesis. This is the subject of the VASCO 2 project (2015-2018), which will implement a marine algae production system over several hectares in the Mediterranean. The food or transport energy markets could be targeted.

IFREMER

URBAN DEVELOPMENT

Future habitats are being designed today. Our cities and administrations must face up to a number of challenges raised by climate change constraints. Energy, transport, urban planning and health are particularly concerned.

For **urban areas,** the challenge of climate change consists in providing **solutions that target different scales** at the same time, along with multi-scale solutions. For example, urban heatwaves, especially within 'heat islands', are a **public health** issue. Instead of air conditioning, less dense layouts could be considered, such as the **greening of cities,** which in turn places new constraints on **sanitation** and **transport** systems. In **rural** areas, the issues require even more complex optimizations, combining the long-distance transport of people and goods, and coordination with urban systems at various scales. Other problems associated with climate change are specific to coastal areas (rising sea levels), flood-risk areas (recurrent flash floods) and mountain areas (vulnerable areas), etc.
All these regions have significant human activity.
The solutions sought must therefore address the overall issue by using multi-disciplinary approaches that bring together sociologists, economists, urban planners, and specialists in engineering sciences.

© Claude Joanni/IFSTTAR

Low-footprint construction frees up space for vegetation.

© Pascal Taburet/Météo-France

Improvised bathing in Paris during the heatwave of 26 July 2012.

FOCUS

ADAPTING CITIES TO CLIMATE CHANGE

WHAT

BETTER URBAN LIVING

Sprawling or compact? Greener? Solar powered? Tomorrow's cities will shift to new architecture, and the behaviour of their inhabitants must change.

CNRS MÉTÉO FRANCE

Many researchers are working on essential strategies for adapting cities to climate change. France is at the cutting edge in this field, in particular with the MUSCADE project (urban modelling and adaptation strategies to anticipate energy demand and production), which brings together several research teams from various disciplines, including meteorologists, built environment specialists, economists, architects and geographers. At its heart is the interaction between climate change, energy in cities and their expansion from today to 2100. This provides valuable tools for the designers of tomorrow's cities.

Projections for the city of tomorrow were made by combining climate and macroeconomic assumptions, such as the price of energy, economic growth and demographic changes, along with assumptions regarding changes in urban areas (sprawling or compact cities), construction and decentralized energy production techniques (greening, solar panels).

The initial results were made public in October 2014 in Paris, during the Chaleur sur la Ville (urban warming) conference.

> *"The overall energy consumption of a city is strongly affected by its inhabitants' behaviour."*

Sprawling cities

An urban heat island (UHI) is an urban area that is significantly warmer than its surrounding rural areas. While this is little affected by urban expansion strategies, the study noted that inhabitants would have reduced thermal comfort in a compact city, due to the concentration of people in the centre of the urban area. Furthermore, researchers found that the energy consumption of built-up areas is similar for sprawling and compact cities. Ultimately, management of urban sprawl has little effect on greenhouse gases emissions (resulting from building energy consumption), which are much more affected by the technologies used for transport.

How to move towards a greener city?

Despite the recent trend for planting on rooftops and walls, this is not the most effective strategy for greener cities. Although vegetation is key to cleaning city air, it must have its own earth: "Planted roofs have a limited effect on external comfort, although they may improve building insulation," stresses the study.

As vegetation only cools the air in summer if it is regularly watered, local water management systems, with water recovery at the district or building level, become a major issue. Furthermore, "strategies for greening cities are inextricably linked to architectural choices, which restrict the ground surface available". The choice of a low-footprint building is a significant factor in freeing space for vegetation.

Rethinking the use of solar power

Like planted rooftops, and contrary to popular belief, solar panels are no miracle cure. In fact, their use does not significantly reduce the urban heat island effect. However, the large-scale installation of panels on rooftops could compensate for the energy that buildings consume for heating and air conditioning over the year.

Each inhabitant has a role to play

Good habits that residents can adopt include closing shutters during the day in the summer, using air conditioning sparingly, or turning down the heating (aiming for 19°C). The MUSCADE study concluded that the impact of our individual choices is comparable to the effects produced by technical solutions such as insulating buildings or planting green spaces. //

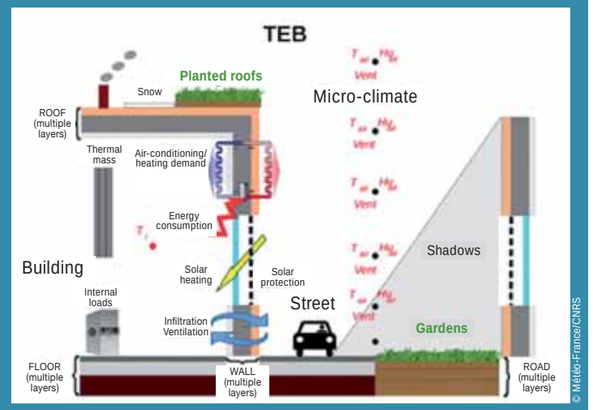
FOR FURTHER INFORMATION
MUSCADE (urban modeling and adaptation strategies to anticipate energy demand and production)
> www.cnrm-game.fr/spip.php?rubrique134

Watch a CNRS video about natural energy for cities (in French)

MODELLING NEW CITIES

NEDUM, GENIUS and Town Energy Balance are three of the computer models used to simulate the 'city system', how it changes over time and processes associated with energy. NEDUM is an urban expansion model based on socio-economic mechanisms from 1900 to the end of the 21st century. Several forecasting scenarios have been studied. The GENerator of Interactive Urban blockS (GENIUS) method concerns the integration of building-scale data into urban microclimate and energy consumption modelling. It can assess the morphology at district scale. The urban microclimate is modelled using Town Energy Balance, which uses physical processes associated with urban layouts. A city's energy consumption is represented by calculating the internal energy balance of buildings.

Computer model of a 'city system'.



© Météo-France/CNRS

AT A GLANCE

Development: taking biosphere-atmosphere interactions into account

A new research programme underway in two French pilot regions is aiming to help development professionals give closer consideration to biosphere-atmosphere interactions in rural development and land management strategies.
The idea is to understand the impact of land occupation and use on the climate and on atmospheric chemistry. Assessments will also make it possible to specify indicators to share with climatologists, meteorologists and development professionals.

AGROPARISTECH INRA CEA CNRS

Paris climate by 2100

The results of the EPICEA project (a multi-disciplinary study of the impact of climate change in the Paris area) show an air temperature increase of 2 to 4°C by the end of the century. This phenomenon varies for different levels of urbanization, such as the city centre, suburbs, and countryside. The trend is towards milder winters and much hotter summers than today.

MÉTÉO FRANCE

© Jean-Marc Prévost/Météo-France

Sacré-Cœur, Paris.

Mitigating urban heat islands

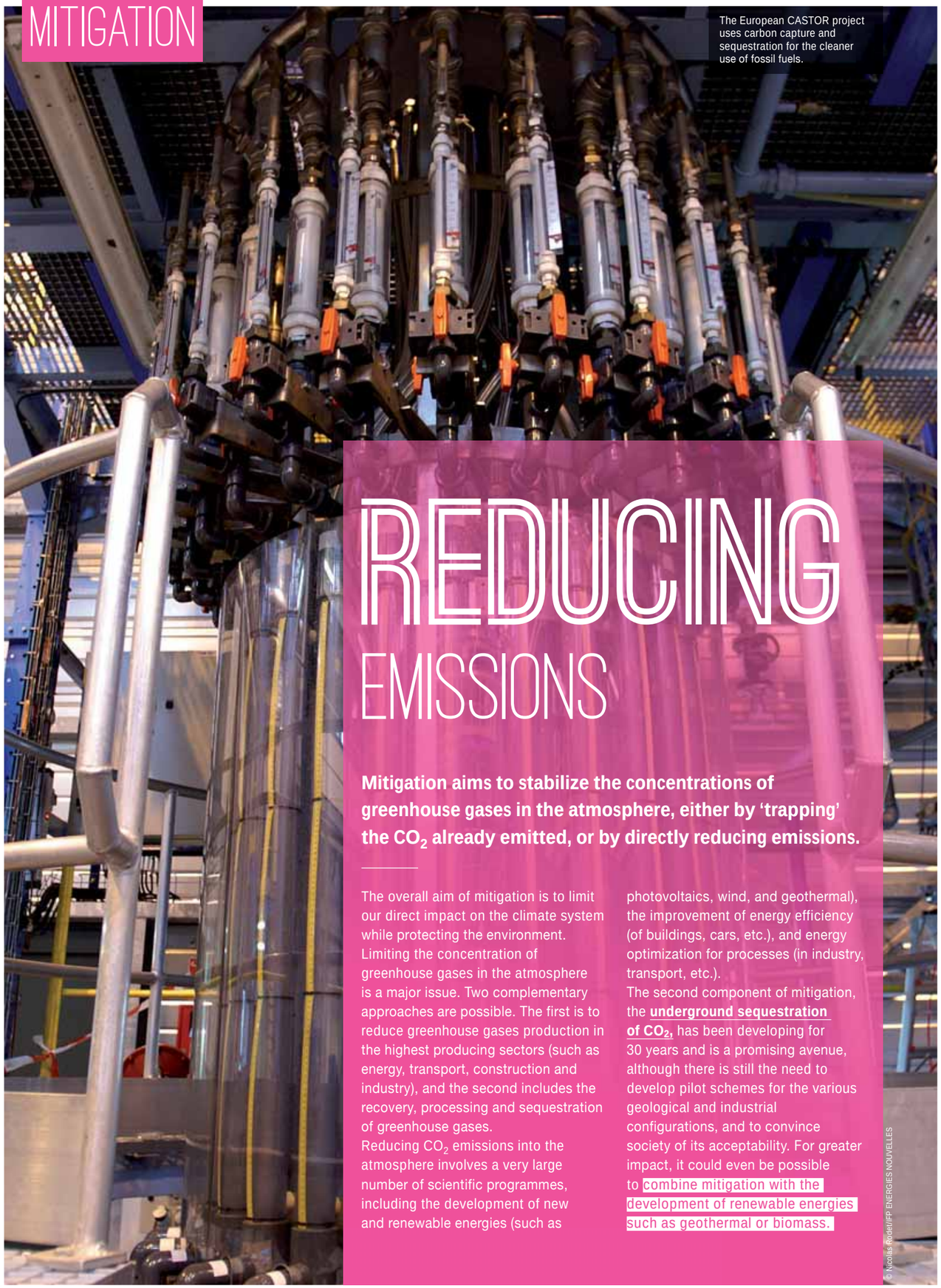
During urban heatwaves, the temperature does not drop at night, and differences of 10°C may be observed between cities and the surrounding countryside. This phenomenon was observed again this year and is known as an urban heat island. It is set to get worse because of temperature increases due to climate change. Urban vegetation should be a good way of mitigating the problem, which leads to thermal stress on the human body. Research is underway on the subject, in particular in Singapore and Paris (such as planted roofs and walls, parks and green corridors). Even urban agriculture may have a role to play.

MÉTÉO FRANCE IFSTTAR

ECORCE 2.0 decision-support tool extended

For many years, civil engineers have expressed the need for assessment tools (methods, baselines, software) for sustainable development.
The aim was to provide decision support for the construction, maintenance and operation of road infrastructure.
The current decision-support tool ECORCE 2.0 (eco-comparator applied to roads, construction and maintenance) implements life-cycle assessment (LCA) for road infrastructure, in its construction and maintenance phases. There is good news for those who work in the sector: its functions are to be extended.

IFSTTAR



The European CASTOR project uses carbon capture and sequestration for the cleaner use of fossil fuels.

REDUCING EMISSIONS

Mitigation aims to stabilize the concentrations of greenhouse gases in the atmosphere, either by 'trapping' the CO_2 already emitted, or by directly reducing emissions.

The overall aim of mitigation is to limit our direct impact on the climate system while protecting the environment. Limiting the concentration of greenhouse gases in the atmosphere is a major issue. Two complementary approaches are possible. The first is to reduce greenhouse gases production in the highest producing sectors (such as energy, transport, construction and industry), and the second includes the recovery, processing and sequestration of greenhouse gases.
Reducing CO_2 emissions into the atmosphere involves a very large number of scientific programmes, including the development of new and renewable energies (such as photovoltaics, wind, and geothermal), the improvement of energy efficiency (of buildings, cars, etc.), and energy optimization for processes (in industry, transport, etc.).
The second component of mitigation, the **underground sequestration of CO_2,** has been developing for 30 years and is a promising avenue, although there is still the need to develop pilot schemes for the various geological and industrial configurations, and to convince society of its acceptability. For greater impact, it could even be possible to combine mitigation with the development of renewable energies such as geothermal or biomass.

© Nicolas Rodet/IFP ENERGIES NOUVELLES

FOCUS

CO_2 CAPTURE AND SEQUESTRATION

Underground CO_2 sequestration is one of the solutions for reducing greenhouse gases emissions into the atmosphere. However, its consequences must be understood and its viability tested.

IFP ENERGIES NOUVELLES | IFSTTAR | BRGM | CNRS

Although capturing CO_2 and reinjecting it into geological cavities is interesting from an economic perspective, French scientists explain that "the viability of the solution requires detailed understanding of the short- and long-term consequences of CO_2 injection into geological formations". Deep geological formations provide natural 'reservoirs' for disposal and confinement, over several hundred years, including empty oil and gas wells, deep saline aquifers and coal seams.

Research has focused on characterizing reservoirs, the consequences of CO_2 injection and the development of systems to prevent any risk of gas leakage from the reservoir, which could pose a risk to people, ecosystems and groundwater. Scientists are also studying how 'injectability' (the ability to inject CO_2) would change over time, "as any reduction could limit the economic and technical durability of the operation". This could be caused by various phenomena such as micro-cracking in porous environments, deterioration of the sealant used over time, acid attacks after CO_2 injection, or natural or artificial geological discontinuities.

Mastering the technology chain

Scientists are also developing expertise in each link in the technology chain, from gas processing to underground reinjection. Capture methods tested include post-combustion and oxy-combustion.

Impressive figures back this up. In 2006, the European CASTOR project launched a world-first pilot project for CO_2 capture at the Dong Energy coal-fired power plant in Esbjerg in Denmark. It demonstrated the ability to capture 90% of the CO_2 emitted by a coal-fired power plant through the use of suitable solvents.

However, there is still the problem of the legal and financial frameworks, which are not yet in place, and society is still reticent regarding the idea of developing CO_2 sequestration. Potential deployment of this technology depends on political decisions. //

Watch the CASTOR animation – *CO_2 capture pilot project*

SOFTWARE FOR SAFER SEQUESTRATION

Researchers are developing software and technology to safely sequestrate CO_2. Their work involves site characterization, estimating sequestration capacities, risk analysis, optimizing CO_2 injection and geochemical monitoring using seismic signals.

AT A GLANCE

Algae, the biofuels of tomorrow

Micro-algae have a photosynthesis yield high enough for biofuel production. Researchers have developed a micro-algae production process combined with that of biogas, known as the Algotron. This new-generation process for bioenergy production can strongly rival that of other biofuels.

INRA

Deadly micro-organisms

Nitrous oxide (N_2O) is a powerful greenhouse gases that is also responsible for destroying the ozone layer. The ability of soils to eliminate N_2O is well known. Researchers have demonstrated that this can be explained by the diversity and abundance of a new group of micro-organisms, capable of reducing it to nitrogen gas (N_2). These results underline the importance of microbial diversity in soil functions and the services it provides.

INRA

CO_2 sequestration in cultivated soil

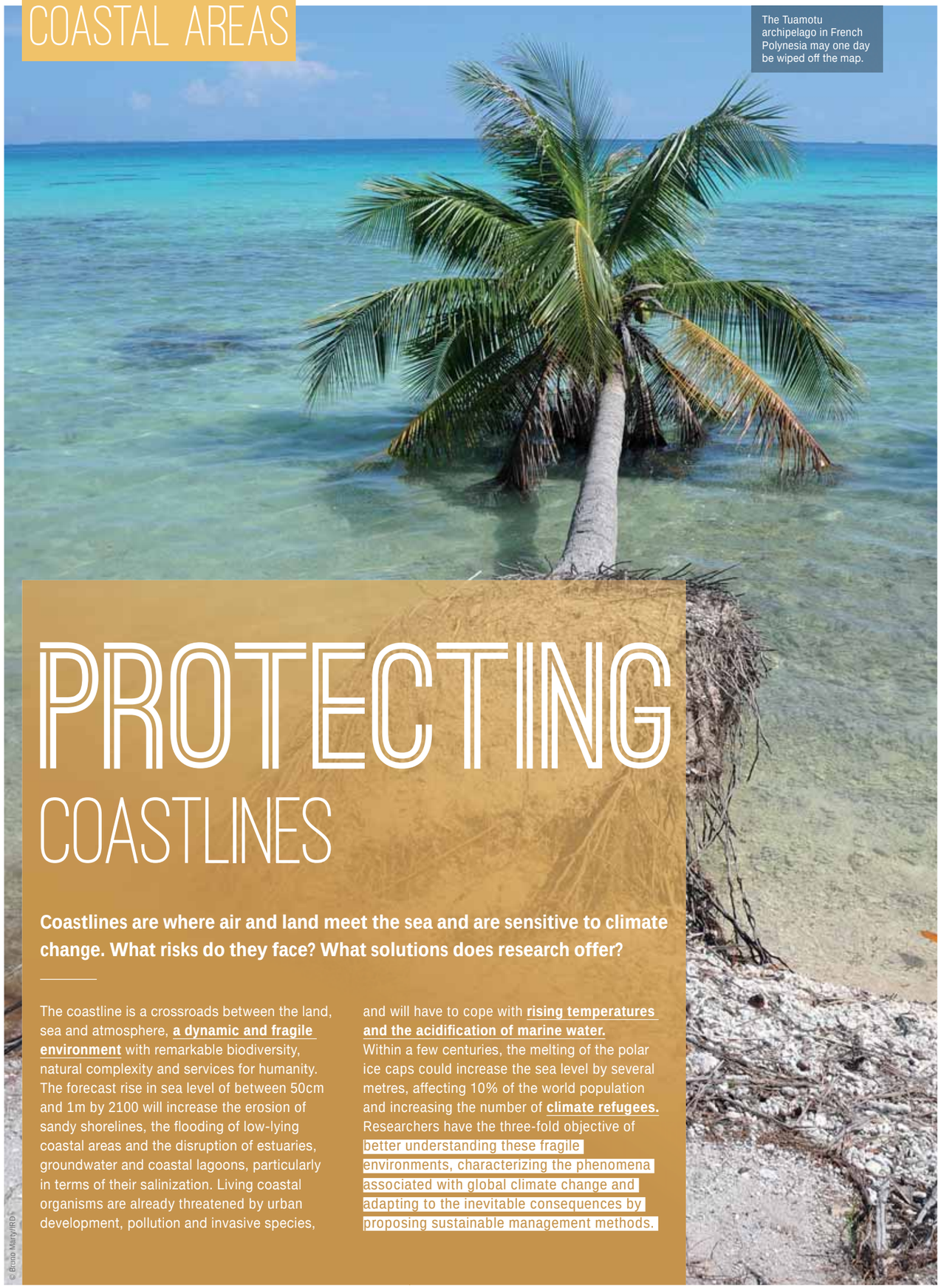
Agriculture produces about 23% of greenhouse gases emissions. With the help of French researchers, the Food and Agriculture Organization (FAO) has developed a method of adopting cropping techniques that promote carbon sequestration. They quantified greenhouse gases emission and storage in the cultivated soils of tropical regions and developed the Ex Ante Appraisal Carbon-Balance Tool (EX-ACT) for calculations and to help decision-making. It assesses environmental projects, systems or policies by estimating the impacts of soil use and changes in use.

IRD

A food supplement for ruminants!

The level of atmospheric CH_4 (methane) has more than doubled over the last two centuries, mainly due to human activities, in particular raising cattle. Methane is a greenhouse gases 25 times stronger than CO_2. Use of a feed supplement from the fermentation of a cereal by a fungus of the Monascus *genus, reduces ruminant methane production by 30%.*

INRA



The Tuamotu archipelago in French Polynesia may one day be wiped off the map.

© Bruno Marty/IRD

PROTECTING COASTLINES

Coastlines are where air and land meet the sea and are sensitive to climate change. What risks do they face? What solutions does research offer?

The coastline is a crossroads between the land, sea and atmosphere, **a dynamic and fragile environment** with remarkable biodiversity, natural complexity and services for humanity. The forecast rise in sea level of between 50cm and 1m by 2100 will increase the erosion of sandy shorelines, the flooding of low-lying coastal areas and the disruption of estuaries, groundwater and coastal lagoons, particularly in terms of their salinization. Living coastal organisms are already threatened by urban development, pollution and invasive species, and will have to cope with **rising temperatures and the acidification of marine water.** Within a few centuries, the melting of the polar ice caps could increase the sea level by several metres, affecting 10% of the world population and increasing the number of **climate refugees.** Researchers have the three-fold objective of better understanding these fragile environments, characterizing the phenomena associated with global climate change and adapting to the inevitable consequences by proposing sustainable management methods.

FOCUS

HOW CAN WE ADAPT TO THE CONSEQUENCES OF THE IRREVERSIBLE RISE IN SEA LEVEL?

New tools are available to identify the most vulnerable coastal zones in France. They are used to anticipate impacts and implement adaptation measures.

BRGM CNRS

© BRGM

Following storms in December 2013 and January 2014, alarming erosion occurred in Soulac-sur-Mer, Aquitaine.

Since 2011, the rising sea level has been taken into account in coastal risk regulations. A 60cm rise in sea level must now be taken into account in coastal zone development programmes. This regulatory change is a significant example of an early adaptation measure that specifically focuses on one inevitable consequence of climate change.

For this measure, research is required to provide tools to answer the following questions: what are the most vulnerable areas? Should we expect significant intensification of coastal risks from 2040, 2070 or 2100? Can the anticipated changes be modelled? How can changes to the frequency and intensity of marine flooding be assessed? French researchers have developed new tools to better assess the consequences of rising water levels and help the relevant stakeholders to adapt.

Diagnostic tools to identify the vulnerability of coastal sites

Work performed under various research projects on the topic of 'Identifying critical sites and time periods related to the impacts of rising sea level' has already helped to better identify how climate change can have varied effects on different coastal sites.

Researchers have introduced diagnostic tools to assess the vulnerability of coastal zones at various time scales (2050, 2100, etc.). These forecasting systems take into account rising sea levels, its regional variations, the local geomorphological and geological context, land use and human activities. These approaches have been applied in Aquitaine and Languedoc-Roussillon and on Réunion Island, areas which, in some cases, have already been severely affected by coastal erosion and sea flooding. //

AT A GLANCE

The Loire estuary: what does the future hold?

Estuaries are fragile areas subject to reduced flowrates, increased risk of flooding, salt water ingress and silt movement. How will their saline and turbid content and morphology change? Tests using hydro-geomorphological modelling for different estuary types attempted to answer this question by studying estuary changes according to various climate scenarios. This study is now the basis for testing alternative methods for managing marshland used for extensive grazing or hunting activities (special case study in the Loire Estuary).

IFREMER

Land rezoning

How will the areas threatened by coastal risks be rezoned? It is important to have information on current and future marine flooding phenomena. The town of Hyères-les-Palmiers is carrying out a research project whose developments could be applied elsewhere. It involves exploring rezoning options for coastal areas (communities, transport, activities) on the basis of flooding risk predictions using high-resolution dynamic models (1m). This study illustrates the advanced capability of current modelling tools and the relative influence of hydrodynamic factors for 2030 and 2100.

BRGM

Modeling storms to within 10cm

Which coastal zones would potentially be flooded during storms if the sea level rose by 20 to 60cm? This is very complex to assess due to the extensive spatial variability of extreme water levels during storms. However, a recent research programme helped improve current hydrodynamic models to reach a level of accuracy to within less than 10cm. These unrivalled levels of precision help better model the effects of storms.

CNRS BRGM MÉTÉO FRANCE

ANTICIPATING

THE RISKS ASSOCIATED WITH CLIMATE CHANGE

Coastal flooding, heavy rain and extreme floods, sinkholes and landslides are just some of the many natural risks that accompany climate change and its major consequence, rising temperatures. Risks are the combination of potential hazards and vulnerabilities, and are key international issues.

Hazards (such as earthquakes, flooding, storms, and forest fires) are not just random events. As research and technology progress, experts are now able to identify causes, analyze and quantify these phenomena, and even predict them, at least in the short term. **Vulnerability,** which is related to land development, is also the subject of study for researchers aiming to reduce it. For example, this could mean preventive measures (such as adaptation of urban areas, or enhanced technical specifications for construction), supplemented by crisis management, public protection and warning systems and the deployment of special measures.
Risks are studied by scientists as an overall entity. They affect whole spheres of political, social and economic life.
In particular, the issue is to change the behaviour of communities in the face of risks, which raises the question of property rights, for example when confronted with rapid coastal erosion or with regard to construction permits for areas at risk of flooding.

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IFREMER's oceanography ship Pourquoi pas? during the GEOVIDE campaign off Canada.

© T. Lebel/IRD

The NMR method being tested in the Alps.

FOCUS

IN SEARCH OF LOST WATER UNDER GLACIERS

WHAT

PREVENTING GLACIAL RISKS

Over 99% of the Earth's fresh water exists in ice formations or underground. French geophysicists have developed an innovative method based on nuclear magnetic resonance (NMR). It is used for preventing the risks associated with the accumulation of meltwater under glaciers due to global warming.

IRD

Our planet's fresh water is difficult to detect, with 99% of it hidden in ice or underground. This is particularly true in semi-arid regions where this major resource is hidden from view underground.

Although hydrologists have invasive methods for detecting and quantifying groundwater, exploration techniques using individual soundings or boreholes are expensive and not precise enough to estimate the volume of water available in an aquifer. Geophysicists have therefore developed indirect surface-based exploration techniques. These are based on the propagation and deformation of electrical or magnetic waves. However, they are not always sufficient to detect groundwater.

Faced with this lack of precision, a team of French researchers, in collaboration with Israeli scientists, has developed a new method based on nuclear magnetic resonance (NMR). This led to an unexpected application in the field of preventing glacial risks in Haute-Savoie in eastern France. In June 2010, new 3D software was used to estimate the volume of water stored under the Tête Rousse glacier to be 55,000m^3, which is the equivalent of around 20 Olympic swimming pools! This presented a significant risk for the villages below. The authorities organized its artificial drainage, at over 3,200 metres in altitude. In all, 48,000 m^3 of water was pumped out, with the remaining volume no longer presenting a threat. In 1892, 175 people died when a glacier wall burst, due to a similar pocket of water. Similarly, in 1988, Lake Sabai Tsho in Nepal suddenly emptied, destroying everything in its path. NMR now means that we can avert catastrophe!

This phenomenon is explained by the fact that meltwater is usually drained both by surface streams and by flows under the ice which emerge downstream of the glaciers. In some cases, this subglacial flow is blocked and water remains trapped under the ice. Hence the notion of a pocket, which is now quantifiable thanks to NMR. This is a timely discovery, as climate change may be weakening the ability of glaciers to hold back such pockets.

Measuring the magnetic field of water in rocks

"Currently, this is the only surface-based technique capable of detecting liquid water below ground or under a glacier and estimating its volume," say researchers.

In contrast to soundings or boreholes, NMR is a non-intrusive method. The water studied is located at approximate depths of 0 to 100 metres. An alternating current generated by researchers at the ground surface creates an electromagnetic field which in turn triggers the resonance of the water molecules held in the rock underground. This magnetic field is then measured.

> *"A technique for prevention of deep-water risks in semi-arid and mountainous regions."*

The NMR method is used only for detecting quantities of underground water, unlike traditional geophysical techniques that analyze anomalies in structures or physical parameters.

NMR has demonstrated its effectiveness in quantifying hidden water resources in many tropical regions. It has also found an unexpected application in mountains, where water can become trapped under glaciers, forming a subglacial pocket. If the glacier wall fails, this can directly threaten inhabited areas below. The only solution is to drain the water pocket before its sudden release. The NMR method has thus proved to be applicable in many regions across the world. //

FOR FURTHER INFORMATION

A. Legchenko, M. Descloitres, C. Vincent, H. Guyard, S. Garambois, K. Chalikakis, M. Ezersky. THREE-DIMENSIONAL MAGNETIC RESONANCE IMAGING FOR GROUNDWATER, *New Journal of Physics*, 2011, 13, pp.025022.

Watch a video on Mediterranean karst systems (in French)

AT A GLANCE

More frequent forest fires

*A group of researchers aims to characterize changes to the risk of **forest fires in France based on the Forest-fire Weather Index (FWI).** Global warming is expected to increase this risk. A comparative study of the 1961-1980 and 1989-2008 periods shows a marked increase in mean FWI over the whole country, with a 22% increase over the year and a 24% increase in summer. There is also a very marked local increase: the index can reach 20 in some southern areas such as Herault and Southern Corsica. It is feared that this may **mean a longer wildfire season and** an increase in the number of regions **affected by forest fires.***

MÉTÉO FRANCE

Permafrost risks

Typical of arctic regions, permafrost is soil that has been frozen for thousands of years, representing 25% of the Northern hemisphere landmass. It is gradually defrosting due to global warming, in turn releasing powerful greenhouse gases, mainly CO_2 and methane. This phenomenon has been widely underestimated in climate models. Researchers are working to model gaseous emissions: old carbon is in the process of being released into the atmosphere!

CNRS

© Laure Caillouce/CNRS Photothèque/Takuvik

Thermokarst ponds (here seen covered in snow), caused by thawing permafrost (Nunavik in the Canadian Arctic)

Anticipating natural risks in mountainous areas

*The RHYTMME project (from the French acronym for hydrometeorological risks in Mediterranean mountainous areas), combines a network of next-generation radars and a web platform for mapping hydrometeorogical risks. Along with the cumulative rainfall maps provided by the radars, users have real-time access **to the maps produced by a flooding risk** warning system. Other mountain hazards can be viewed on the platform **such as the risk of debris flows,** landslides and rockfalls. The aim is to predict hazardous phenomena in mountainous areas, whose frequency could increase with climate change.*

IRSTEA MÉTÉO FRANCE

© Patrice Ménaux/IRSTEA

Next-generation RHYTMME radar in the Southern Alps.

Air quality: possible scenarios

Using large-scale multi-model comparison, a comprehensive study on air quality has estimated changes in atmospheric composition due to climate change, for both gases and aerosols, over the 1850-2100 period. Ozone has increased sharply since 1850. According to the various scenarios studied, changes by 2030 and 2100 show different trends: an optimistic scenario predicts a reduction by 2030, while in others the reduction occurs between 2030 and 2100, except for one scenario in which tropospheric ozone concentration continues to rise steeply.

MÉTÉO FRANCE CNRS

Rainfall monitoring: mobile phones are taking over

Rainfall monitoring is vital in many research fields (hydrological, climate and agricultural modelling), and operations (such as meteorology, water supply services, food security, and flood and drought warnings). However, observation networks remain insufficient. This is not the case for mobile phone networks, which provide coverage over 20% of the planet's landmass and 90% of the world's inhabited areas. Besides transmitting radio signals, they record signal disturbances, which are partly due to precipitation, in order to monitor the quality of networks. The idea of the researchers is to benefit from this data to improve rainfall monitoring and spatialization. The method has just proved its effectiveness in Burkina Faso, where it was found to be 95% reliable in detecting rainfall events.

IRD

THE ALLIANCE

AT THE HEART OF CLIMATE CHANGE RESEARCH

The French Alliance for Environmental Research (AllEnvi) organizes French environmental research, steers its agenda and promotes it on the international scene and with private stakeholders and civil society.

→ Pooling French environmental research. **Created at the initiative of its 12 founder members, AllEnvi represents a community of some 20,000 scientists.**

→ Tackling the environmental challenges facing society. **The Alliance brings together and directs all French environmental research to tackle global change issues. In particular, it acts to plan sustainable adaptations in advance, begin the ecological transition and explore avenues for green growth.**

→ Acting at the heart of the national research strategy. **The Alliance defines the major priorities for French environmental research. Its strength lies in pooling the breadth of expertise and using a cross-sector, multi-disciplinary systems approach to environmental issues.**

The 12 founder members

The French Geological Survey
As the national geological survey, the BRGM is the key public body in the field of earth sciences, for managing soil and subsoil resources and risks.
www.brgm.fr

Alternative Energies and Atomic Energy Commission
The CEA operates in four major fields: low-carbon energies, IT and healthcare technologies, large-scale research infrastructure, defence and global security.
www.cea.fr

The French agricultural research and international cooperation organization
In partnership with diverse countries, CIRAD produces and shares new knowledge to support agricultural development and contribute to the debate on major issues in global agriculture.
www.cirad.fr

French National Centre for Scientific Research
The CNRS operates in all fields of knowledge, with over 1,200 laboratories. It is the primary partner of higher education and research institutions in France, and a major player in research at the European and international levels.
www.cnrs.fr

Conference of University Presidents
The CPU gathers the top leaders of universities and other higher education and research institutions to include the input and values of universities in public debate. It currently has over 120 members: university presidents, directors and general administrators of other institutions (such as écoles normales supérieures, INPs and INSAs) and associate members.
www.cpu.fr

French Research Institute for Exploitation of the Sea
IFREMER contributes to the knowledge of oceans and their resources, to monitoring marine and coastal environments and to sustainable development of maritime activities. To achieve this, it designs and develops observation, experimentation and monitoring tools. Since 2008, IFREMER's ships have been part of the TGIR (very large research infrastructure) oceanographic fleet.
www.ifremer.fr

French Institute of Science and Technology for Transport, Development and Networks
IFSTAR performs mission-oriented research work and consulting in the areas of transport, infrastructure, natural risks and urban planning, to improve the living conditions of our fellow citizens, and more generally, to promote the sustainable development of our societies.
www.ifsttar.fr

National Institute for Agricultural Research
As the leading agricultural research institute in Europe, INRA produces scientific knowledge in three fields: food, agriculture and the environment, with the aim of helping to sustainably feed the world.
www.inra.fr

Institute of Research for Development
The IRD is a unique research body within the European research landscape, performing research in, for and with developing countries.
www.ird.fr

National Research Institute of Science and Technology for Environment and Agriculture
IRSTEA is a Carnot-certified institute which develops mission-oriented research in partnership with and for public authorities and socio-economic stakeholders, to support them on water issues (resources, quality and risks), green technologies and land management.
www.irstea.fr

Météo-France
The National Meteorological Service, Météo-France has several major missions including: development and maintenance of an observation network, gathering and processing climatological data, weather forecasting, making climate projections, and research and training in various fields relating to weather and climate.
www.meteofrance.com

National Museum of Natural History (MNHN)
The MNHN is a public cultural, scientific and professional institution. Since its creation in 1635, it has been devoted to understanding and preserving biodiversity and to the relationship between humankind and the natural world.
www.mnhn.fr

The 16 associate members

The French Agricultural, Veterinary and Forestry Institute
www.agreenium.org

National Radioactive Waste Management Agency
www.andra.fr

National Agency for Food, Environmental and Occupational Health & Safety
www.anses.fr

Conference of the Directors of French Engineering Schools
www.cdefi.fr

Center for Studies and expertise on Risks, Environment, Mobility, and Urban and Country Planning
www.cerema.fr

Conference of *Grandes Écoles*
www.cge.asso.fr

National Centre for Space Studies
www.cnes.fr

Foundation for Research on Biodiversity
www.fondationbiodiversite.fr

IFP Energies nouvelles
www.ifpenergiesnouvelles.fr

National Institute of Geographic and Forestry Information
www.ign.fr

National Competence Centre for Industrial Safety and Environmental Protection
www.ineris.fr

National Institute for Computer Science and Applied Mathematics
www.inria.fr

French Polar Institute Paul Emile Victor
www.institut-polaire.fr

National Institute for Radiological Protection and Nuclear Safety
www.irsn.fr

National Laboratory of Metrology and Testing
www.lne.fr

Hydrographic and Oceanographic Department of the French Navy
www.shom.fr

AT THE HEART OF NATIONAL RESEARCH STRATEGY

AllEnvi

French Alliance for Environmental Research

AllEnvi was created on 9 February 2010 at the initiative of 12 founder members, and is one of five thematic research alliances

12 FOUNDER MEMBERS

16 ASSOCIATE MEMBERS

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