CNES MAG

EN FR

SPACE ● INNOVATION ● SOCIETY

#93
July 2022

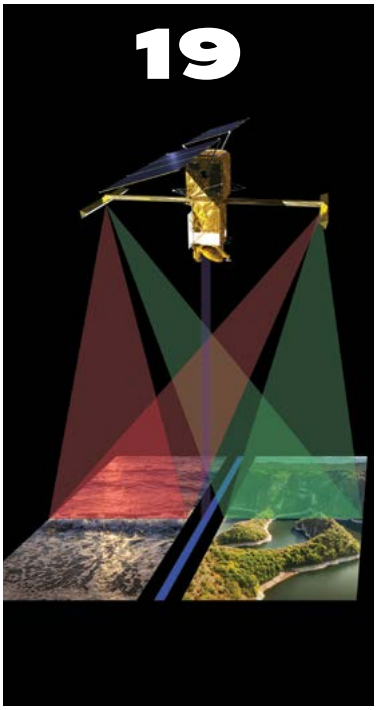
SWOT

PLANET WATER

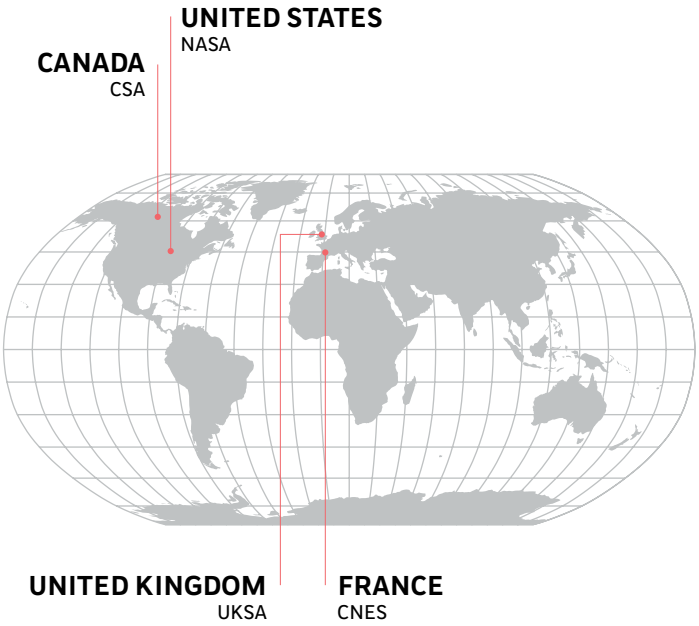
cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

INSIDE

INSIDE



SPACE AGENCIES COLLABORATING ON SWOT



PARTNERS

In this issue: CERFACS (European Centre for Research and Advanced Training in Scientific Computation) p 10; Airbus Defence & Space p 10; CLS (Collecte Localisation Satellites), a CNES subsidiary, p 10-18-32; European Union p 11-23; European Space Agency (ESA) p 11; CSIRO, Australia's national science agency p 18; GFZ, the German research centre for geosciences p 25; CS Group p 18; IGN national mapping, survey and forestry agency p 18; ONERA national aerospace and defence research agency p 18; CNRS national scientific research centre p 21; IRSTEA national research institute for environmental and agricultural sciences and technologies p 21; IRD sustainable development research institute p 21-25-35; LEGOS space geophysics and oceanography research laboratory p 21-22-25; OiEau International Office for Water (IOW) p 21-35.

WWW.CNES.FR
More content in this new issue online at cnes.fr/cnesmag

CNESfrance
@CNES
YouTube CNES

CONTRIBUTORS

THIERRY LAFON

Thierry Lafon has been involved with the SWOT programme from day one and it holds no secrets for him. He is acutely aware of the urgency of helping science and his fellow humans in the crucial task of managing water resources. As project leader, he oversees the technological and administrative sides. With the satellite soon set to launch, he takes legitimate pride in sharing this human and technological adventure with us.

NICOLAS PICOT

With Jason-2, SARAL/AltiKa, the Sentinel satellites and now SWOT, Nicolas Picot has been casting a keen eye over the quality of altimetry products for more than 20 years. Nothing escapes his attention, be it the features or performance of instruments and processing systems. The enduring ties he has forged with the scientific community have been key to the success of the SWOT-Aval early adopters programme, whose benefits he explains for us here.

SELMA CHERCHALI

The health and status of the planet's oceans and rivers are a constant concern for Selma Cherchali as she devotes her boundless energy to tackling the impacts of our changing climate. She has been very active in the Space for Climate Observatory (SCO) since 2018, leading among other things programmes focused on Earth's environment and hydrology. The head of the Earth Studies and Observation sub-directorate of CNES's Strategy Directorate was only too glad to be of service for this issue of Cnesmag.

SERGE DELMAS

An academic and a globetrotting photographer, Serge Delmas has travelled the world following numerous space missions and to satisfy his natural curiosity. As the agency's Earth-observation communication officer, he casts a clear eye on the state of the planet and in particular on water issues. He shared his perspective and helped us to choose the emblematic locations inside this issue.

CNESMAG

CNESmag, the magazine of the Centre National d'Etudes Spatiales, 2 place Maurice Quentin. 75039 Paris cedex 01. For all correspondence, write to: 18 avenue Edouard Belin. 31401 Toulouse cedex 9. Tel.: +33 (0)5 61 27 40 68. Internet: http://www.cnes.fr. This review is a member of Communication&Entreprises. Subscriptions: https://cnes.fr/reabonnement-cnesmag. **Publication director:** Philippe Baptiste. **Editorial director:** Marie-Claude Salomé. **Editor-in-chief:** Brigitte Alonzo-Thomas. **Proofreading:** Céline Arnaud. **Editorial staff:** Brigitte Alonzo-Thomas, Aude Borel, Liliane Feuillerac, Dominique Fidel, Guillaume Tixier. **Photos and iconography:** Marie-Claire Fontebasso. **Photo editor:** Thierry De Prada. **Photo credits:** p.4 CNES/T. De Prada; p.5 CNES/C. Peus; p. 6 NASA Earth Observatory image by Lauren Dauphin/MODIS; p.7 (top) EU COPERNICUS MARINE&CLIMATE SERVICES/CNES/LEGOS, 2022; p.7 (bottom) CNES/F. Maligne; p.8 (top) SCO Space for Climate Observatory; p.9 Getty Images; p.10 (top) AFP/MUNIR UZ ZAMAN; p.10 (bottom) Gwilhmet Primel; p.11 Getty Images; p.13 Agence H2e/Emmanuel Layani; p.15 Agence-H2e/ Emmanuel Layani; p.16 AFP/BIJU BORO; p.17 Getty Images/De Agostini; p.18 Copernicus Sentinel Data, 2022; p.19 Thales Alenia Space, 2021; p.20 CNES/Thales Alenia Space/L. Barranco, 2019; p.22 Ocean/NEXT: https://github.com/ocean-next/eNATL60; p.23 (top) Getty Images; p.23 (bottom) CNES/O. Sattler; p.24 CNES/Distribution Airbus DS, 2019; p.25 ESA; p.26 CNES/Distribution Airbus DS, 2014; p.27 CNES/Mira Productions; p.33 J. Arnould; p.34 (top right) Lycée Victor Duruy/Bagnères de Bigorre; p.34 (bottom left) CNES/E. Grimault, 2022; p.35 Yves Barou/DJibril Sy/website yvesbarou.fr; p.36 vorteX.io. **Illustrations:** Jean-Marc Pau, gettyimages. **Webmaster:** Sylvain Charrier, Mélanie Ramel. **Social media:** Mathilde de Vos. **English text:** Boyd Vincent. **Design and pre-press:** Citizen Press – David Corvaisier, Fabienne Laurent, Alexandra Roy, Guillaume Tixier. **Printing:** Ménard. ISSN 1283-9817. **Thanks to:** Alice Andral, Christophe Brachet, Pierre Boutte, Frédéric Bretar, Pierre-Marie Brunet, Philippe Collot, Sophie Coutin Faye, Jean-François Crétaux, Isabelle Fratter, Flavien Gouillon, Emline Deseez, Francesco d'Ovidio, Roger Fjortoft, Benoît Laignel, Anne Lifermann, Pena Luque Santiago, Florent Lyard, Philippe Maisongrande, Rosemary Morrow, Jean-Christophe Poisson, Amélie Proust, Estelle Raynal, Anna Salsac, Annick Sylvestre-Barron, Guillaume Valladeau.

PEFC 10-31-2690

IMPRIM'VERT

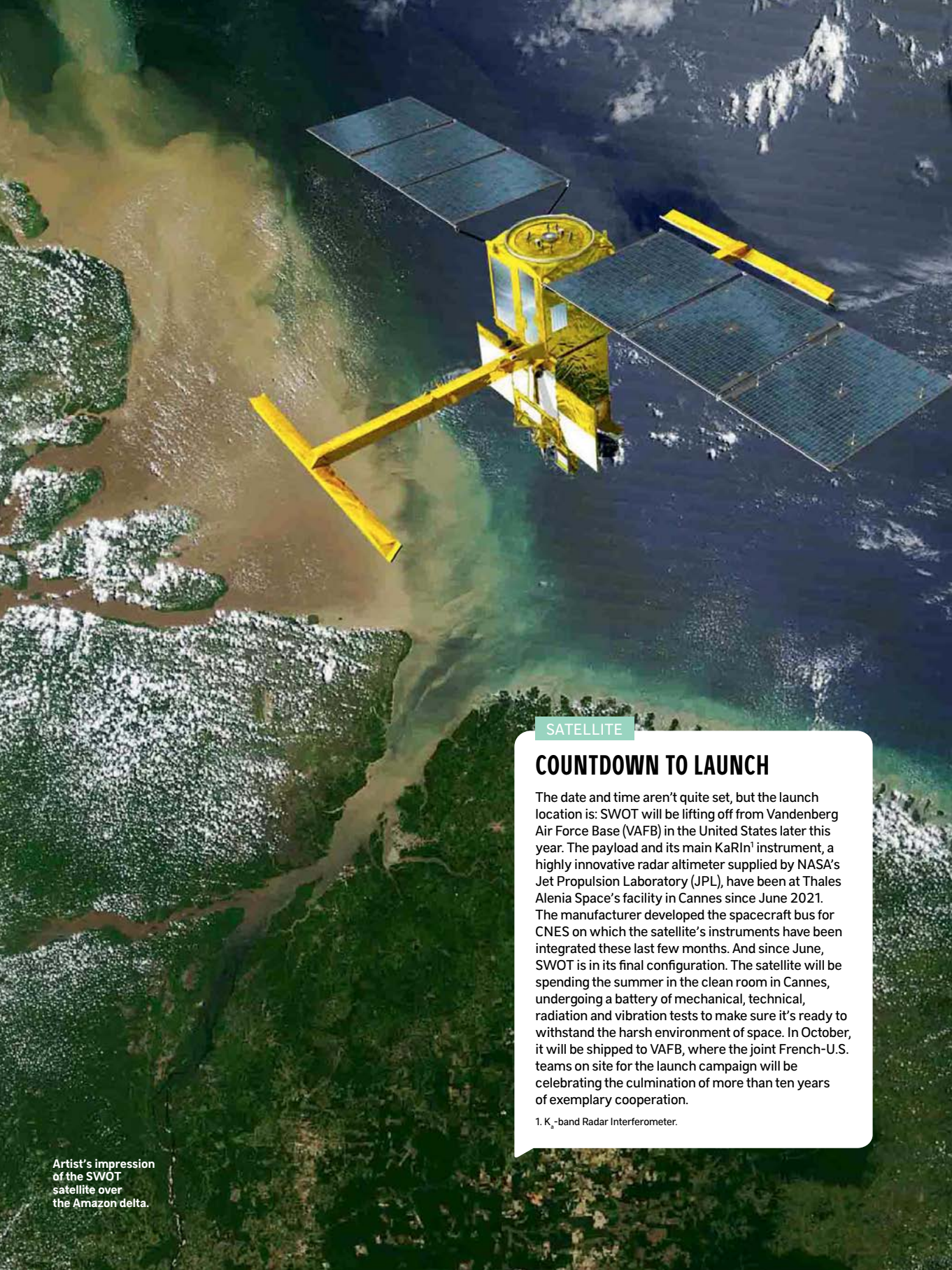
The Blue Marble is the name coined from the famous photograph of Earth taken in December 1972 by the Apollo 17 mission crew. Our planet owes its blue colour to the oceans covering more than 70% of its surface. These oceans absorb the Sun's rays, regulate the temperature of the atmosphere, capture carbon, transport heat via currents, and produce by evaporation the clouds that bring us rain, snow and freshwater. They are in large part responsible for the emergence of life on this planet, and the guarantors of its survival. But with the disruption of Earth's climate, we are eyeing the oceans' health with increasing concern and their role must be defined in greater depth. We need to understand these underlying mechanisms and what is causing them to spiral out of control. To do that, we have to shift our scale of analysis from the wider global picture to local micro-phenomena.

This is precisely the goal of the French-U.S. SWOT mission. Packed with technological innovations in altimetry and interferometry, SWOT is set to advance our understanding of the full water cycle with a number of firsts. In the field of hydrology, it's going to establish the first-ever inventory of surface waters, measuring water heights and discharges, gauging global freshwater stocks and monitoring the drying up of lakes and water courses. In the field of oceanography, with a resolution ten times better than current technologies, it will enable fine-scale observations spanning hundreds to tens of kilometres of ocean eddies, filaments and their interactions, thus refining our knowledge and prediction models. And thanks to its radar interferometer instrument, SWOT will let scientists study the hydrodynamics of complex coastal zones for the first time.

Readily integrated with existing products, SWOT data are going to enhance our climate models and help us to better predict and prepare for the impacts of climate change—a matter that concerns us all.

I hope you enjoy reading this issue of Cnesmag.

MARIE-CLAUDE SALOMÉ
CNES DIRECTOR OF COMMUNICATION



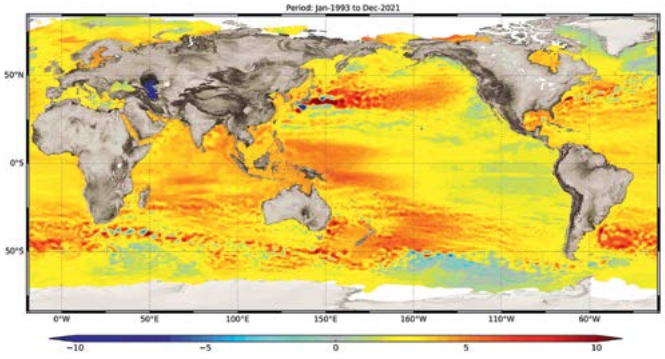
SATELLITE

COUNTDOWN TO LAUNCH

The date and time aren't quite set, but the launch location is: SWOT will be lifting off from Vandenberg Air Force Base (VAFB) in the United States later this year. The payload and its main KaRIn[1] instrument, a highly innovative radar altimeter supplied by NASA's Jet Propulsion Laboratory (JPL), have been at Thales Alenia Space's facility in Cannes since June 2021. The manufacturer developed the spacecraft bus for CNES on which the satellite's instruments have been integrated these last few months. And since June, SWOT is in its final configuration. The satellite will be spending the summer in the clean room in Cannes, undergoing a battery of mechanical, technical, radiation and vibration tests to make sure it's ready to withstand the harsh environment of space. In October, it will be shipped to VAFB, where the joint French-U.S. teams on site for the launch campaign will be celebrating the culmination of more than ten years of exemplary cooperation.

1. K_a-band Radar Interferometer.

Artist's impression of the SWOT satellite over the Amazon delta.



Change in sea level from January 1993 to September 2021, based on data from the high-precision TOPEX/Poseidon, Jason-1-2-3 and Sentinel-6 altimetry satellites.

OPERATIONAL OCEANOGRAPHY

A FRENCH-U.S. SUCCESS STORY

The ocean's turbulent motions have long taxed the minds of scientists. In the 1980s, to analyse these mechanisms and anticipate their effects, CNES and NASA each began working on an altimeter concept to measure surface water and wave height and winds.
The Americans concentrated their efforts on TOPEX, while the French focused on Poseidon, an instrument designed to equip the first SPOT satellite. In 1983, they joined forces and officially embarked on the TOPEX/Poseidon project, sealing their partnership through a memorandum of understanding in 1987. From then on it went from strength to strength: launched in 1992, the mission highlighted the seasonal El Niño phenomenon in 1994 and its devastating effects, with drought and crop failures in Africa, and floods and tumbling coffee prices in South America. TOPEX/Poseidon thus laid the foundations of operational oceanography. Its successors, notably Jason-1 to 3 and Sentinel-6, have delivered a wealth of ocean data. And with SWOT, CNES and NASA are giving satellite altimetry a wonderful present to mark its 30th anniversary.

14,000

New SWOT high-resolution products that will be listed in the hydroweb.next catalogue every day, representing 7 terabytes (7 million megabytes).

FUNDING

STRONG AND CRUCIAL SUPPORT

The ambitious SWOT mission wouldn't have seen the light of day without a significant budget boost of €160 million from the government's PIA future investment programme set up in 2018 to fund innovative and promising projects. In addition to this, CNES provided €190 million from its own government subsidy, taking the total French contribution to one-third of the mission's cost[1]. This significant investment has enabled the agency and its partners to play a foundational role in the programme. CNES is in charge of the spacecraft bus, KaRIn's radiofrequency unit (RFU), the Poseidon 3 dual-frequency nadir altimeter and the DORIS precise orbit determination system. It is also providing a satellite command-control segment and a data processing centre. The SWOT processing centre has been tailored to deliver highly innovative technological solutions and to handle the massive amounts of data from the satellite and distribute them through the dedicated hydroweb.next hydrology portal. By encouraging uptake of these data, CNES will also be stimulating the space ecosystem and numerous start-ups—a factor that was instrumental in obtaining PIA funding.

1. €350 million out of $1 billion.

OpHySE

FOCUSING ON FRENCH GUIANA'S RIVERS

The Maroni and Oyapock mark the north-western and southern borders of French Guiana, two socially, politically, economically and environmentally sensitive regions. The two rivers are the only route for transporting goods and people to and from villages upstream. Seven other rivers of over 100 kilometres criss-cross the country, which makes equipping and maintaining a hydrology monitoring network a difficult and costly business. This is where space offers a good alternative.

The OpHySE[1] digital platform tracks river status in real time, gauging their height, discharge and navigability using satellite data from Jason-3, Sentinel-3 to 6 and the GPM[2] constellation. French firm Hydromatters, CNES and end-users—at regional government agencies[3]—are working to get this project moving forward following its accreditation last year by the Space for Climate Observatory (SCO).

1. Operational Hydrology from Space and modEls.
2. Global Precipitation Measurement.
3. Guianese territorial and maritime directorate (DGTM), Guianese water agency.

HYDROWEB.NEXT

HYDROLOGY DATA AT THE FINGERTIPS

SWOT is now in its home straight and CNES is all set to process the stream of data it will be delivering. The hydroweb.next portal is the new gateway to these hydrology products at the Theia land surfaces data hub. The portal will be directly connected to the SWOT mission centre. Besides SWOT products, this spatial water database will be compiling global hydrology data—altimetry data, algorithms, etc.—acquired from space.

The site is open to all for free or on subscription for certain specific products. All available data products are briefly presented, indicating their content, licence, temporal and spatial resolution and producer.

The already comprehensive website is set for a revamp that will provide access to hydrological data from a range of sensors, acquired using space, in-situ and aerial technologies, as well as from numerical models.

LEARN MORE:
HYDROWEB-NG@CNES.FR

STOCK WATER

EYE ON WATER VOLUMES

How do we gauge how much water is stored in the hundreds of thousands of reservoirs dotted around the globe? This information collected and held by local public or private water planning bodies is somewhat random. Stock Water is a solution conceived by CNES and several partners to gain access to these data. Open on a voluntary basis, Stock Water is a global monitoring tool providing weekly water volume indicators to each partner nation, with a dedicated processing system designed for government agencies. Fed by data from the Sentinel-1, Sentinel-2 and TanDEM-X satellites, Stock Water can be accessed via a QR code. It was accredited in 2021 by the Space for Climate Observatory (SCO) and is being trialled in India, Tunisia and Laos. SWOT data will be key to improving product quality.

90%

The SWOT mission will be able to sound 90% of Earth's surface waters (rivers, lakes and reservoirs).

620,000 km

France's rivers run a total combined length of 620,000 kilometres, 430,000 kilometres in mainland France.

1.4

BILLION KM³

Total volume of water on Earth. The volume of freshwater is estimated at 35 million km³ (3% of the total volume), of which 24,000 km³ are used by humans every year.

SATELLITES SURVEYING THE WATER CYCLE

2001 2008 2016
Jason-1-2-3 (CNES/NASA) – Sea-surface height

2009
SMOS (ESA) – Land surfaces – Soil moisture, ocean salinity

2011
Megha-Tropiques (CNES/ISRO, India) – Precipitation, cyclones, monsoons, drought

2015 2016 2020
Sentinel-2-3-6 (EC/ESA) – Land cover, sea and surface water level, navigable water courses, coasts

2018
CFOSat CNES/CNSA, China) – Ocean winds and waves

2022
SWOT CNES/NASA) – Topography of surface waters, oceans and coastal waters

2025
Trishna (CNES/ISRO, India) – Plant evapotranspiration – Coastal water temperature

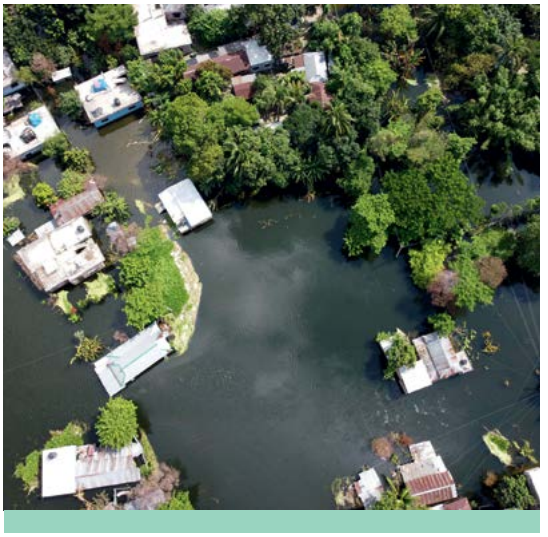
CITIZEN SCIENCE

PHOTOGRAPHING WATER LEVELS

Hiking or fishing? Whatever your preference, water resource management is everybody's business, and by supporting the OECS[1] surface water observation project, you'll be aiding science. How? Quite simply by taking pictures with your phone of the staff gauges on the banks of lakes and rivers. Each one has its own QR code. The measurement in your photo will be added to those already on the oecsmap.org website. This kind of citizen science isn't just a bit of fun, because we lack data on natural lakes and you will be helping to fill the gap. Your field observations will also serve by comparison to verify measurements acquired by the SWOT satellite. OECS is the French strand in partnership with the Adour-Garonne water board of the LOCSS[2] project initiated in the United States. So why not get involved? You'll be joining identical initiatives in places as far away as Canada, India and Bangladesh.

1. Observation des Eaux continentales par des Citoyens et des Satellites.
2 Lake Observations by Citizen Scientists and Satellites.

LEARN MORE:
WWW.OECSMAP.ORG



FloodDAM

ANTICIPATING FLOODS

Flooding is the most common and deadly natural hazard. And it's a risk being compounded by climate change.
The Space for Climate Observatory (SCO) is encouraging implementation of tools to anticipate floods and mitigate their impacts, in particular through the FloodDAM[1] alerting and mapping system.
The result of a partnership between start-up vorteX.io[2] (see Spinoff p. 36), Predict Services[3], CERFACS[4] and CNES, this project is leveraging very-high-resolution imagery from Airbus Defence & Space. CNES subsidiary CLS has designed an automatic rapid flood-mapping system using radar images of flooded areas and model maps. SWOT will simultaneously measure river surface area and water height. Models will enable it to estimate discharges, crucial for activating early-warning systems. The programme has been trialled in several catchment areas around the world, including the Adour-Garonne catchment in Southwest France.

1. Flood Detection, Alert and rapid Mapping.
2. A supplier of innovative measuring instruments.
3. Hazard mitigation and management.
4. European Centre for Research and Advanced Training in Scientific Computation, providing short-range forecasts.

ADOPT A CROSSOVER

INTERNATIONAL SCIENCE PARTNERSHIP

LEARN MORE:
HTTPS://WWW.SWOT-ADAC.ORG/

With its capability to observe phenomena at scales of 7 to 20 kilometres, SWOT is set to provide a new perspective of how the oceans shape climate. The impact of eddies and ocean fronts on marine organisms remains poorly understood, and models do not match observations at all. An offshoot of the SWOT science team, the AdAC[1] consortium is looking to reconcile observations during survey campaigns at sea and SWOT's future measurements. To this end, it will be focusing in particular on points in the ocean where the satellite's ascending and descending tracks cross over. The number of revisits in these zones—up to twice a day—will be at a maximum during the first phase of the satellite's mission life. The AdAC consortium is inviting the world's scientific and academic community to join it in devising and executing experiment protocols to get the most out of SWOT. It is proposing a forum to exchange and pool research on the approach, interpretation and even products that could be developed.

1. Adopt A Crossover.

WISA

ON THE COAT-TAILS OF KARIN

The KaRIn wide-swath radar altimeter (see p. 27) is transforming satellite altimetry and offering a new perspective on the global water cycle. The technology is likely to become a fixture in the payloads of future missions.

Since 2017, in preparation for the European Union's future Copernicus-Sentinel-3NG mission, the European Space Agency (ESA) and CNES have been pursuing complementary feasibility studies based on this technology. The WISA[1] study conducted by CNES, which proposes two satellites to improve revisit rates, is reinvesting this new technology in operational programmes. By broadening the scope of the data, it should also reach more users of future applications.

1. Wide-swath altimetry.

#COMMUNITY

Every day, CNES engages with you on social media and you share your thoughts and questions with us.
Join the conversation!

@THOM_ASTRO

@ESA astronaut 🇪🇺🇫🇷, spacecraft pilot, back on Earth after #MissionAlpha, patron of @ONG_ASF

Two man-made lakes. You can be sure the jagged banks of this lake are because of a dam, as natural lakes' edges are usually smoother. #MissionAlpha

@IMGSAT973

History-geography teacher; PhD grad student at EHESS school of advanced studies in social sciences; interested in using satellite imagery for geography classes

Going back in time with satellites 🛰️: construction of the Atatürk Dam on the Euphrates in #Turkey 🇹🇷 #Turkiye
37°28452''N, 38°19'01''E
Timelapse produced with @sentinel_hub from #landsat 4&5 satellite imagery [1984-1993]
@CopernicusEU @USGSLandsat

@JOELBRUNEAU

Mayor of @CaenOfficiel (#Normandy). President of the @caenlamer Urban Community

Due to its maritime location, @Caenlamer will face many challenges like shoreline retreat and climate change. It's vital that we start thinking now about how to cope with these changes.

@THALES_ALENIA_S

Official Thales Alenia Space account

Hi there, I'm the #SWOT #oceanography satellite. A few weeks ago, I entered a thermal vacuum chamber at @Thales_Alenia_S's #Cannes plant. In orbit, #satellites have to withstand extreme temperatures in vacuum conditions, that's the reason why this test is so crucial @CNES @NASAJPL.

CNESfrance @CNES YouTube CNES

Q & A

EMMA HAZIZA

WITH GLOBAL WARMING, WATER CYCLES ARE INCREASINGLY DISRUPTED EVERY YEAR, bringing flash droughts and torrential rain, and threatening water stocks. Emma Haziza, hydrologist and founder of the Mayane applied research centre, sounds the alarm.

How would you sum up water's place in our lives?

Emma Haziza: Quite simply, we can't live without it. We need water for drinking, to wash and feed ourselves, and more broadly everything we buy uses water. We even depend on this blue gold for our energy, since nuclear and thermal power plants are being shut down for lack of water to cool them. Over time, all these items are becoming increasingly water-intensive. In the space of a century, the world's population has tripled but our water consumption has risen sixfold.

And in that time, mean global temperature has increased by almost 1°C. How is this warming trend affecting the water cycle?

E. H.: Climate disruptions are causing the water cycle to spiral out of control. On all continents, ever-larger regions are seeing a deficit in rainfall. Combined with strong evaporation due to record temperatures, soils are drying on an unprecedented scale and groundwater levels are depleting dramatically. Elsewhere, rainfall episodes are growing more intense as rising temperatures increase the precipitation potential of clouds. Other pernicious factors also have to be taken into account. For example, increased concentrations of atmospheric water vapour contribute actively to the greenhouse effect and therefore to rising temperatures, as water vapour is the principal greenhouse gas. The northern hemisphere is warming three times faster than the rest of the globe, which explains why water giants like Canada are now being hit by the double blow of severe winter flooding and heatwaves fuelling flash droughts.

> "Satellites have enabled us to make giant leaps in our understanding of extreme climate phenomena whose evolution and propagation we can now anticipate."

The second part of the IPPC report released in February makes grim reading, forecasting more severe weather events, droughts, cities under water and so on. What is your take on it?

E. H.: The consequences of climate change have been amplified since the IPCC's last report, with more devastating and more frequent impacts all over the globe. For example, last year half of the world's population experienced water shortages at some time or another. Between 42% and 79% of the world's water catchments are likely to be critically affected by 2050, which will have a significant effect on freshwater ecosystems and security of supply from reservoirs, thus jeopardizing all human activities. Today, we're pushing our water resources to the limit, like in California where they're continuing to supply the United States with lettuce, tapping into fossil groundwater and knowing that it will never be recharged.

And France won't escape this trend?

E. H.: France is already there. Since 2014, we've seen a succession of record temperatures and significant droughts. Last year seemed to break the trend with more abundant rainfall over large areas of the country, and torrential rains and storms with sometimes dramatic consequences in Germany and Belgium. But elsewhere record temperatures continued unabated, like in Spain, and there were wildfires in Algeria and Greece. This year isn't looking any better. The lack of rain from January to April means that groundwater wasn't recharged. We had the hottest May on record since the Second World War and the early heatwave in June is a very bad sign. We're headed for a historic drought that's going to be disastrous not only for farmers but also buildings, energy and industrial productivity.
And things aren't going to get better anytime soon: for several years now, we've been in a La Niña pattern that

EMMA HAZIZA

HYDROLOGIST AND FOUNDER OF
THE MAYANE APPLIED RESEARCH CENTRE

"I hope future space missions will tell us more about 'green' water."

cools the planet, but according to the latest models that could flip within the next six months to an El Niño episode that always fuels a rise in temperatures.

Where can our understanding of the water cycle be improved, and how can satellite imagery help to achieve this?

E. H.: Since the 1990s, satellites have enabled us to make giant leaps in our understanding of extreme climate phenomena whose evolution and propagation we can now anticipate. For scientists studying the water cycle, space hydrology tools have become key companions supplying ever-more precise, frequent and varied data.
We have learnt a great deal about the dynamics of oceans and the 'blue' water of rivers, lakes and groundwater. I hope future space missions will also tell us more about the 'green' water stored in the upper layers of the soil that plants depend on for their survival and growth.
This is a hot-button issue right now, after the publication by research scientists at the Potsdam Institute of results suggesting that we've now exceeded the safe limit of the planetary boundary for green water, setting in train a process of aridification.

What in your view are the priority measures we need to apply to tackle the effects of climate change?

E. H.: In France, we're quite good at forecasting big river floods.
We've also learnt to take into account how clay soils expand and contract in our land planning strategies.
However, there are other areas where we're still poorly prepared although we know the phenomena are going to become more frequent and more intense, for example the effects of high temperatures on concrete structures or urban run-off.
Besides mitigation measures, it's urgent that we start thinking about how to adapt our society to future climate conditions. There are many things we can do. In agriculture to begin with, which in summer consumes up to 80% of France's water supplies. It's time to rethink our lifestyles through the prism of water consumption and our exposure to climate change impacts: are our homes, cities and consumption compatible with tomorrow's climate?

PROFILE

2007
PhD in hydrology and psycho-sociology of organizations in the face of extreme events from the École des Mines engineering school in Paris.

2010
Founds Mayane applied research centre dedicated to climate change adaptation.

2020
Founds Mayane Labs digital solutions development platform.

2021
Member of the scientific committee of France Ville Durable, board member of Eau de Paris, the capital's water board.

CLIMATE: BANGLADESH

May 2022: heavy pre-monsoon rains lash northern and central Bangladesh. The Surma and Kushiyara, the two main rivers bordering India, break dykes and levees. The levels of the country's 14 major rivers are dangerously high. Even the capital Dhaka doesn't escape the worst flooding the country has seen in 20 years, leaving 60 dead and more than four million seeking shelter. There are 1½ million children at greater risk from water-borne diseases. The latest IPCC report and experts confirm that climate change is increasing the frequency, violence and unpredictability of flooding in Bangladesh. SWOT will enable scientists to refine impact studies and help define coping scenarios for populations.

GEOPOLITICS: LAKE CHAD

From 1970 to 1980, Lake Chad receded by 90% according to records kept at the time. But measurements were sparse, intermittent and even biased or partial due to cross-border management of resources. Decades later, studies based on continuous and frequently refreshed satellite data, conducted by CNES and the IRD sustainable development research institute, show this reservoir is no longer drying up; indeed, its extent and storage capacity have been increasing since 2003. This recovery is encouraging from a hydrology perspective and crucial to the geopolitics of a territory torn by conflict. SWOT will enable the levels of surrounding rivers to be measured to track recharging of the lake.

Early adopters

New technologies, new measurements.

To prepare potential users of future SWOT products, in 2018 NASA and CNES formed a community of Early Adopters, in other words not scientists but end-users looking for real-world benefits from the satellite's data. Depending on the practical applications being sought, these Early Adopters are combining simulated SWOT data with other available indicators to gauge the added value the future mission is going to bring. Their observations are fuelling exchanges and encouraging key adjustments. For example, data turnaround times have been shortened from 45 to just three days. Early Adopters at the Indian Institute of Technology (IIT) Bombay have integrated SWOT and Sentinel-1 measurements in a flood prediction map, while the Compagnie Nationale du Rhône (CNR) in France has also used simulated SWOT measurements for hydroelectricity energy budgets and to forecast navigability in rivers where instruments are scarce.

AQUAWATCH AUSTRALIA

Initiated by CSIRO[1] in partnership with SmartSat CRC and a range of national and international organizations including space agencies, AquaWatch Australia will monitor the quality of the country's continental and coastal waters. This forecasting structure will measure key water variables and provide early warning of severe events. It will track and supply information on ecosystems under threat, the quality of inland and coastal waters, and habitat conditions. This national service will thus help end-users such as water planners and contractors to make informed decisions.

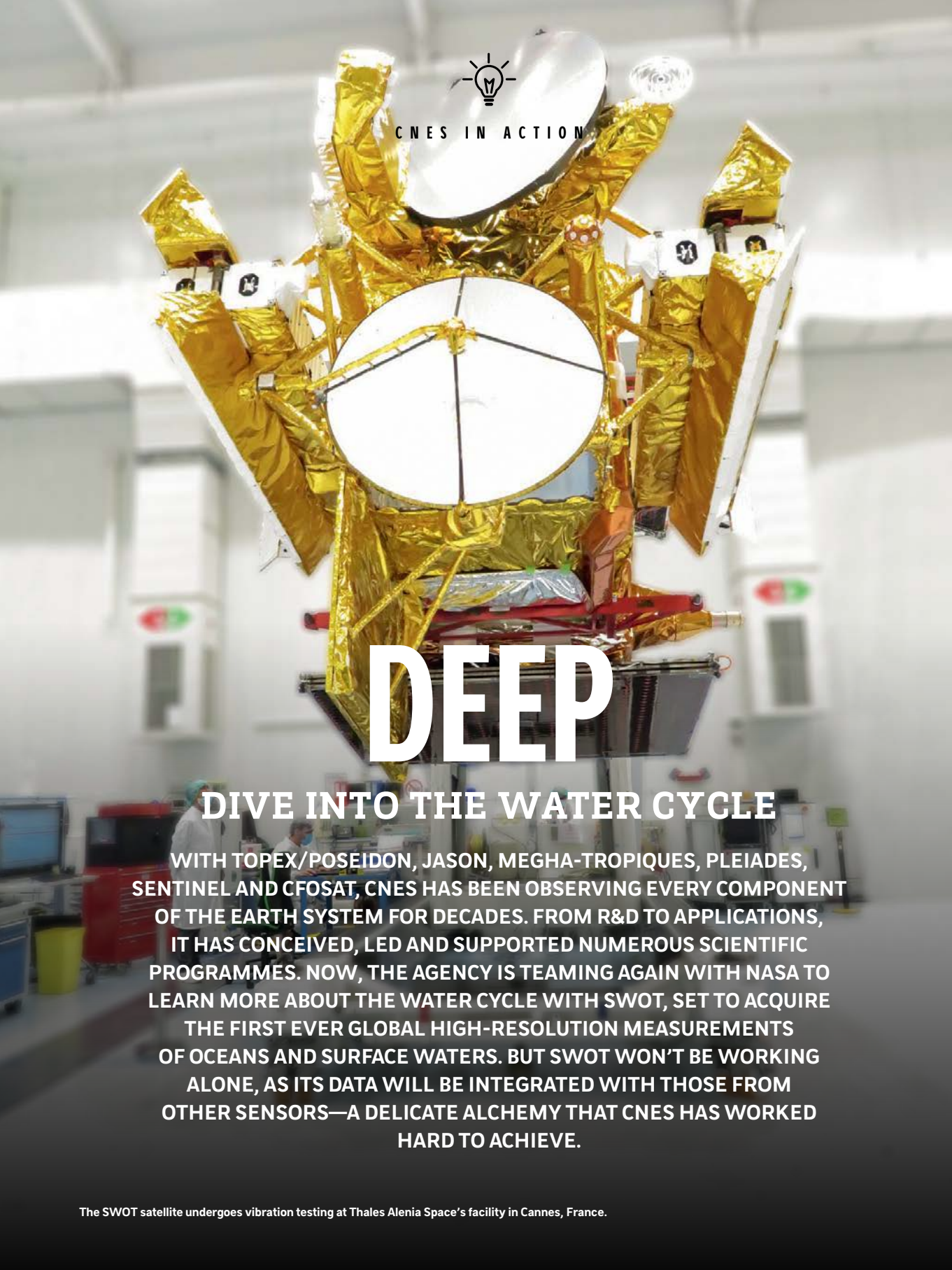
1. Commonwealth Scientific and Industrial Research Organisation, the Australian national science agency

4

ACCESS TO WATER AND ITS MANAGEMENT GO TO THE HEART OF THE SUSTAINABLE DEVELOPMENT GOALS (SDGS) in the United Nations Agenda 2030. The SWOT mission is set to contribute to four of these 17 SDGs selected by France. Inventorying of surface waters, evaluations of stocks and regular monitoring of water volumes will provide real-time data to guarantee clean water and sanitation for all (SDG 6). SWOT will complement existing satellite data to support conservation of marine resources and keep a check on fisheries (SDG 14). To a lesser extent, it will help ensure access for all to reliable energy services, as tight management of reservoirs and their capacity is required for production of more sustainable energies like hydroelectricity (SDG 7). Lastly, by enabling scientists to study fine-scale ocean/atmosphere interactions, SWOT will support urgent climate action measures (SDG 13).

AI4Geo

HOW CAN we get the most out of the plethora of geospatial data out there? Backed by the government's PIA future investment programme, AI4Geo is an R&D programme coordinated by CS Group. CNES, national mapping, survey and forestry agency IGN and national aerospace and defence research agency ONERA are contributing satellite data and expertise. The aim is to automate production of geospatial information. To do that, AI4Geo is banking on artificial intelligence to turn satellite data into extremely precise 3D maps. Alongside its research work, AI4Geo is developing application demonstrators, some of which are focused on the water cycle and led by CLS.



DEEP

DIVE INTO THE WATER CYCLE

WITH TOPEX/POSEIDON, JASON, MEGHA-TROPIQUES, PLEIADES, SENTINEL AND CFOSAT, CNES HAS BEEN OBSERVING EVERY COMPONENT OF THE EARTH SYSTEM FOR DECADES. FROM R&D TO APPLICATIONS, IT HAS CONCEIVED, LED AND SUPPORTED NUMEROUS SCIENTIFIC PROGRAMMES. NOW, THE AGENCY IS TEAMING AGAIN WITH NASA TO LEARN MORE ABOUT THE WATER CYCLE WITH SWOT, SET TO ACQUIRE THE FIRST EVER GLOBAL HIGH-RESOLUTION MEASUREMENTS OF OCEANS AND SURFACE WATERS. BUT SWOT WON'T BE WORKING ALONE, AS ITS DATA WILL BE INTEGRATED WITH THOSE FROM OTHER SENSORS—A DELICATE ALCHEMY THAT CNES HAS WORKED HARD TO ACHIEVE.

The SWOT satellite undergoes vibration testing at Thales Alenia Space's facility in Cannes, France.

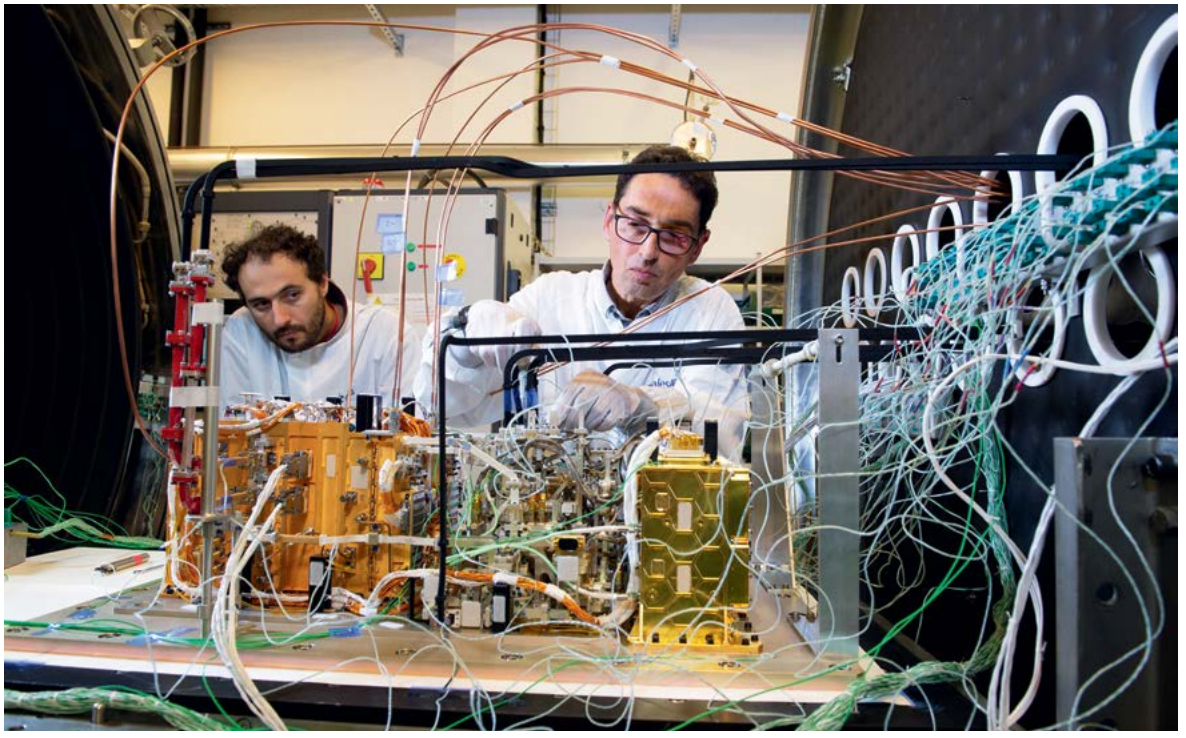
Back in the 2000s, CNES's Scientific Programmes Committee (CPS) outlined a future priority mission to observe water around the globe, with a particular focus on inventorying surface waters and understanding their dynamics. As luck would have it, at around the same time its counterpart across the Atlantic was pursuing similar priorities through its Decadal Survey. Ten years after their collaboration on TOPEX/Poseidon, CNES and NASA thus signed a new implementing arrangement in September 2010, with a clear red line: the new mission would in no way seek to replicate TOPEX/Poseidon, but rather rely on forward-looking disruptive technologies. This would be achieved by resurrecting the concept of wide-swath altimetry, previously tested and shelved by the U.S. agency. The mission's main KaRIn instrument, a K_a-band[1] radar interferometer (see p. 27), extends the swath covered to 120 kilometres and affords a tenfold gain in resolution over existing technologies.

300

A hundred scientists in France and more than 300 worldwide are contributing to the SWOT mission, considered even before it is launched as revolutionary.

DATA MANAGEMENT EXPERTISE

This prestigious mission also comes at a cost, estimated at $1 billion, two-thirds of it covered by NASA. Backed by the French government's PIA future investment programme, CNES is contributing funding as well as its expertise and that of its partners (see p. 6). A dense network of ground stations will communicate with SWOT, while the control centre in Toulouse will keep a close eye on the mission. "But our strong suit is our expertise in data management," explains Thierry Lafon, SWOT mission leader at CNES. "SWOT is going to generate vast quantities of data to be collected, processed, stored and distributed." This expertise also gives CNES an advantage in negotiations. NASA is supplying the main KaRIn instrument, while the Canadian Space Agency (CSA) is contributing



Inside the Radiofrequency Unit (RFU), France's contribution to the KaRIn instrument.

extended interaction klystrons (EIKs) that will generate and amplify microwave pulses for KaRIn and the United Kingdom Space Agency (UKSA) is providing part of the instrument's radiofrequency unit (RFU).

WORKING WITH THE SCIENTIFIC COMMUNITY

The SWOT-Aval early adopters programme (see opposite) is another key French contribution. The SWOT science group is led by an active research community of hydrologists and oceanographers from the national scientific research centre CNRS, the IRSTEA national research institute for environmental and agricultural sciences and technologies, the OIEau International Office for Water (IOW), the IRD sustainable development research institute and the LEGOS space geophysics and oceanography research laboratory, whose suggestions, simulations and models have helped to refine mission specifications. They will be playing a key role, particularly in the calibration and validation phases after launch, using shipborne sensors and data buoys to compare multisource data with those from SWOT and ultimately guarantee the reliability of SWOT products for future users.

SPRINGBOARD FOR THE SPACE ECOSYSTEM

Just as it has called on the support of the scientific community, CNES is relying on the industrial base of which it is a core player. "Through these prestige missions, CNES is enabling industry to hone its skills and acquire visibility in the global market," notes Thierry Lafon. Thales Alenia Space (TAS), which designed the first Poseidon altimeter in 1990, is an emblematic example. The manufacturer has built on this success to become a world leader in satellite altimetry, carrying a number of SMEs in its wake such as Steel Electronique, Avantis for structures and ground support equipment, Nexeya for wiring harnesses and Soditech for thermal control systems. TAS is the prime contractor for SWOT, in charge of spacecraft bus construction and payload integration, as well as supplying the Poseidon 3 nadir altimeter and the radar core of the mission's main instrument.

The main return on investment from SWOT will be for our planet, as between the mission's definition in 2010 and its forthcoming launch, global warming has stepped up a gear, as the latest report from the IPCC[2] makes abundantly clear. Combined with data from other sources, SWOT will advance science to inform public actions. We can also expect to see rapid development of citizen applications for keeping an eye on Earth's ecology and climate.

1. Frequency band used for satellite Internet services.
2. Intergovernmental Panel on Climate Change.

Early adopters

THE OTHER SWOT REVOLUTION

The first SWOT revolution is technological; the second is the SWOT-Aval early adopters programme. Conceived at a very early stage in the project, this programme has drawn on a set of multisource data from satellites, in-situ sensors and hydrology and oceanography models. Backed by the PIA future investment programme, it is aimed at future users. CNES has succeeded in bringing on board a worldwide community ready to leverage future SWOT data, promoting the mission at multiple forums, symposia and summits[1], organizing workshops in French Guiana and Congo, conducting field surveys and analysing needs. It has pushed experts and research laboratories to share their knowledge. Demonstrators have also been developed, like NASA's AirSWOT airborne instrument to acquire interferometry measurements similar to those SWOT will be collecting in space, complemented by numerous data simulators. A hydrology portal has been set up by the Theia land surfaces data hub, giving users—water boards, manufacturers, farmers, etc.—access to the full range of hydrology information. SWOT-Aval is also looking further ahead, with working groups of research laboratories, scientists and public and private stakeholders already imagining the value-added services and applications that SWOT is set to bring.

1. 8th World Water Forum in Brasilia (2018) and Manaus 2019, Water from Space in South America in Santiago, Chile (2018), 9th World Water Forum in Dakar (2022).

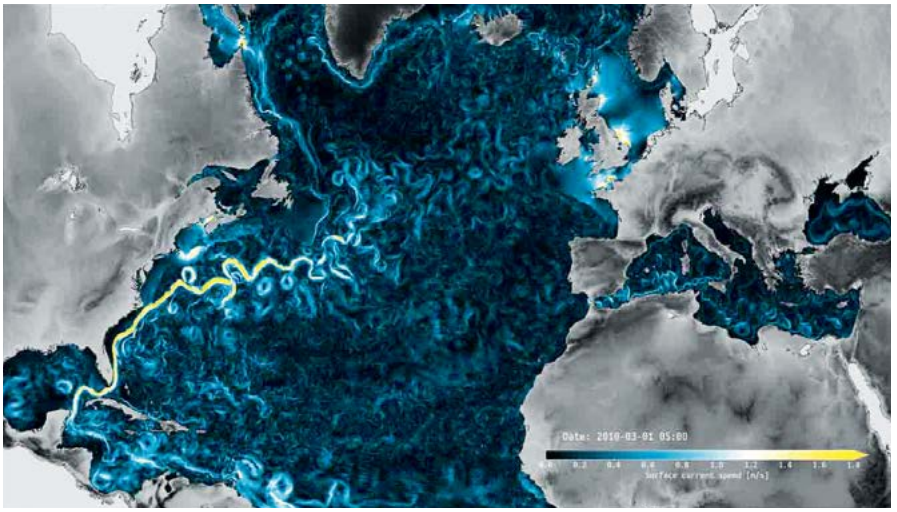
billion

More than 20% of the world's population—about 1.6 billion people—live less than 30 kilometres from the coast.

Oceanography

THE DEVIL IS IN THE DETAILS

Thirty years of satellite altimetry have given oceanographers a broad picture of how the oceans work, but there are still grey areas that SWOT could shed new light on.



This very-high-resolution ocean model developed by teams at Grenoble University's IGE environmental geosciences institute provides a picture of ocean dynamics (major currents, eddies, internal tides, etc.) that will aid analysis of SWOT data quality once the satellite is in orbit.

Ocean circulation is a key cog in Earth's climate machine. The oceans absorb more than 90% of excess heat in the atmosphere generated by global warming, but more than 50% of vertical heat transfer is driven by fine-scale ocean processes. Today, these phenomena remain hard to observe. "Traditional altimetry has advanced our knowledge of ocean bottom topography, high- and low-pressure zones and the global ocean circulation," notes Rosemary Morrow, SWOT oceanography science lead at the LEGOS space geophysics and oceanography research laboratory. "We've been able to observe large-scale phenomena like the Gulf Stream, El Niño and the big ocean eddies, so we know how they work."

1.4X10²¹

litres

Estimated total volume of water on Earth, of which the oceans make up 97%.

TURBULENCES UP CLOSE

Successive missions from Jason-1, 2 and 3 to Copernicus[1] Sentinel-3 have detected large and energetic eddies more than 100 kilometres across, and their effects on temperature, salinity, water quality and more besides. But today, the planet-wide climate emergency is forcing us to push our investigations further. "It's vital to understand what's going on at finer scales[2] and mesoscales[3]," says Morrow. For the devil, as so often, is in the details: it's inside the core of these small features that certain disruptions are thought to originate and where we hope to gain deeper insights into mechanisms we couldn't observe until now, like turbulences, filaments, small eddies and friction zones. Variations in sea-surface height at different points in the ocean also affect ocean circulation and Earth's climate. How can these small-scale phenomena spanning no more than ten kilometres have such a big impact on global ocean circulation and affect seasonal variations on the other side of the world? How do they interact with each other? What roles do they play in ocean mixing and vertical 'pumping'? And what influence do

they have in the transport of carbon and nutrients, and in dispersion of pollutants at the surface and in the ocean depths? SWOT will help to answer these questions and provide scientists with the information they need to gauge the impacts on biogeochemical cycles, micro-organisms and plankton.

FROM MODELLING TO ASSIMILATION

SWOT will provide answers in the form of data. The mission is set to deliver scientists new and complementary measurements with ten times better resolution and 3D images. Its observations will also rapidly benefit operational climate monitoring services. Global ocean forecasting structures like Mercator Ocean or the European Union's Copernicus Marine Environment Monitoring Service (CMEMS) are at the top of the list, provided nevertheless that SWOT data can be integrated and assimilated with conventional altimetry products—a condition that appears well on the way to being satisfied. The first simulations are reassuring, showing that SWOT data will indeed be capable of being integrated in existing climate models to improve ocean circulation models and, ultimately, better forecast weather and climate conditions.

10.2

million km²

of marine spaces make France the world's second largest maritime area, behind the United States.

1. European Union climate monitoring programme.
2. Approx. 1 to 50 kilometres.
3. From a few kilometres to less than 2,000 kilometres.

Air-sea interface

WIND AND WAVES: THE TERRIBLE TWINS

Thanks to SWOT, oceanographers are getting ready to dive deeper into ocean turbulences. But the satellite will also complement another key mission: the French-Chinese CFOSat, focused on wind and waves. Launched in 2018, this satellite is carrying two radars: SWIM[1], designed at CNES and built by Thales Alenia Space, which measures wave length, height and direction; and SCAT[2], supplied by China to measure wind strength and direction. Data from the two missions will enable research on the air-sea interface, crucial to better understand satellite observations of water temperature and salinity, currents and air-sea fluxes, and to better forecast extreme events at sea and near coasts. Combining multisource data—SMOS, Sentinel-1A and 1B, CFOSat, SWOT, etc.—is the only way to comprehend how the climate machine works.

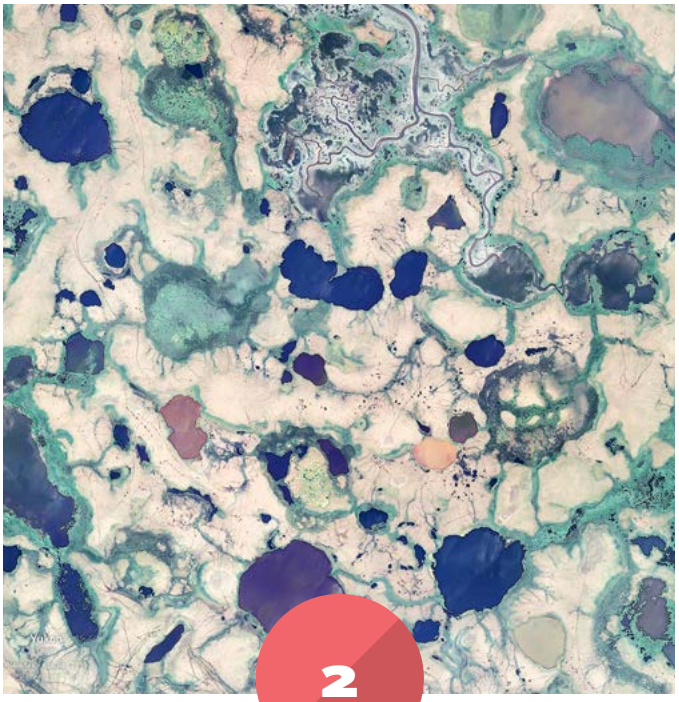
1. Surface Waves Investigation and Monitoring.
2. Wind SCATterometer.

Hydrology

FINDING INFORMATION AT SOURCE

Will we soon be facing water shortages? Are we headed towards a 40% shortfall by 2030? To find out, it's vital to precisely quantify and measure this precious resource to manage it better. SWOT is going to give hydrologists the investigative tools they need to do this.

Yukon, a territory in Northwest Canada dotted with glacier-fed lakes and snow-covered mountains.



2 million

Lakes that SWOT will measure, i.e. the 2 million largest of the 120 million lakes covering more than 0.2 hectares around the globe.

On July 2010, the United Nations General Assembly made access to potable water and sanitation a fundamental human right. This noble aim is however proving hard to achieve, for hydrologists are unable to precisely quantify water everywhere on Earth. While large expanses are well known, how can we more effectively share water from springs, rivers, lakes and wetlands? And from glaciers, snow cover and groundwater? Water masses may shift, be transformed and disappear… So, how do we establish a comprehensive inventory of resources to share them more fairly?

A MULTIFACETED EQUATION

Until now, the resolution of altimetry satellites has precluded detailed observations or a precise global inventory. "Canada, a developed and stable nation, has several hundred thousand lakes containing nearly 20% of the planet's freshwater," notes Jean-François Cretaux, a research scientist at the LEGOS space geophysics and oceanography research laboratory. "But how many exactly? No hydrologist in Canada can tell you!" And this isn't the only problem when monitoring this blue gold. "The open ocean is a well-delimited mass of water that belongs to nobody," says Cretaux, "whereas continental waters are spread far and wide, disparate and belong to nations that manage all or part of catchments with varying degrees of consensus." For example, water from the Rhine catchment basin runs through no fewer than seven countries[1] and an international water board shares its analyses and data. On the other hand, in catchments like the Nile, Tigris and Euphrates, or other major rivers in Asia, cross-border geopolitics fuels conflicts. Another obstacle to inventorying these surface waters is that they are fed by multiple and inconstant sources. "Rainfall isn't the only source feeding into rivers," points out the scientist, underlining the complex interconnections between surface water masses.

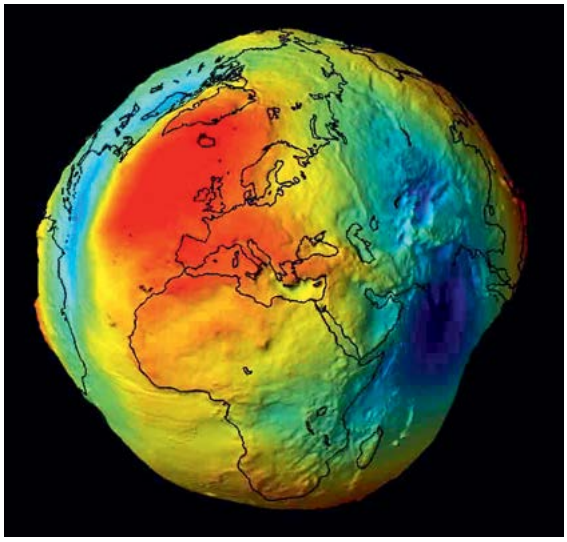
GRACE and GRACE-FO

GOING AFTER GROUNDWATER

For 20 years now, hydrologists have based their estimations of global water masses on the GRACE[1] (2002) and GRACE Follow-On (GRACE-FO, 2018) missions led jointly by NASA and GFZ[2], the German research centre for geosciences.

To determine Earth's gravity field, two satellites fly in tandem in the same orbit at an altitude of 500 kilometres, trailing one another by 220 kilometres. A microwave link measures the distance between them to within a few micrometres. The tandem continuously acquires detailed measurements of variations in the gravity field that give a precise indication of how water masses are distributed and shifting, including below the surface. These missions thus allow scientists to "see underground" and measure variations in soil moisture, groundwater levels and so on. The results obtained show that one-third of the planet's main groundwater reserves are depleting rapidly due to abstraction. All that remains now is to ascertain if stocks are sufficient. GRACE and GRACE-FO are therefore key missions for studying the water cycle.

1. Gravity Recovery And Climate Experiment.
2. GeoForschungsZentrum.



Rivers

wider than 100 metres will be viewed reach by reach; it's estimated that SWOT will be able to observe 200,000 reaches of 20 kilometres across all continents.

SATELLITE DATA AS ARBITERS

"SWOT will be a vital link in the chain to improve our understanding of what's going on at the surface," insists Jean-François Cretaux, the mission's hydrology science lead. It will sound 90% of Earth's surface waters, monitor rivers and map lakes, reservoirs and other water bodies in all weathers. These data will support several types of product (see p. 28). "Thanks to SWOT's revisit capability, we're going to obtain repetitive, global measurements of water levels and stocks, river discharges and surface water extents that were lacking until now, and which would have required several missions combined without SWOT."

SWOT is a cornerstone mission for hydrologists that will supply tangible, undisputable data. In tense cross-border contexts, it could help to adopt objective measures and defuse conflicts. Even before its launch, SWOT is garnering enthusiastic support. In Madagascar, where the IRD sustainable development research agency, CNES and LEGOS were recently conducting calibration campaigns, the satellite is raising water boards' hopes. Their engineers are eager to get working with SWOT data. On a global scale, the mission will have a very real impact in numerous fields such as flood forecasting, potable water resource management, irrigation, river navigation and production of hydroelectricity.

1. Switzerland, Austria, France, Germany, Luxembourg, Belgium and the Netherlands

The Baie d'Authie seen by the Pleaides satellite. Part of the bay's territory on the Côte d'Opale (Opal Coast) was acquired between 1986 and 2003 by the Conservatoire du littoral, the French coastal conservancy. Like all estuaries, it's a haven for marine life but its shoreline is vulnerable to rising sea level and storm submersion, and to local build-up of sand and silt.

Coasts

WATCHING **VULNERABLE ZONES**

Lying at the interface of land and sea, coastal waters are prone to severe weather events putting populations at risk. Conventional satellite altimetry missions don't tell us a lot about these transition zones, as the signal is degraded near the coastline. SWOT is set to change all that.

Coastal regions have always been a magnet for populations and economic activities. Buffeted by winds and tides, their diverse sandy beaches, cliffs, bays, deltas, estuaries, marshes and mangroves, and the rich ecosystems they harbour, are vulnerable to our fast-changing climate.

Scientists haven't waited for SWOT to observe how these areas are evolving and to preserve them, "conducting in-situ surveys that are obviously partial and can't provide the big picture of coastal zones, which are all very different in terms of their shape, nature and hydrodynamics," says Benoît Laignel, the SWOT Science Team (ST) coordinator for these environments.

The spatial coverage afforded by wide-swath radar altimetry will give scientists key information, enabling them to compile global maps, gain new insight into sea level rise and chart the spatial distribution of water heights in all countries. "We'll also get new information on hard-to-forecast phenomena like storms," notes Benoît Laignel, as simulations are already showing.

650

km.

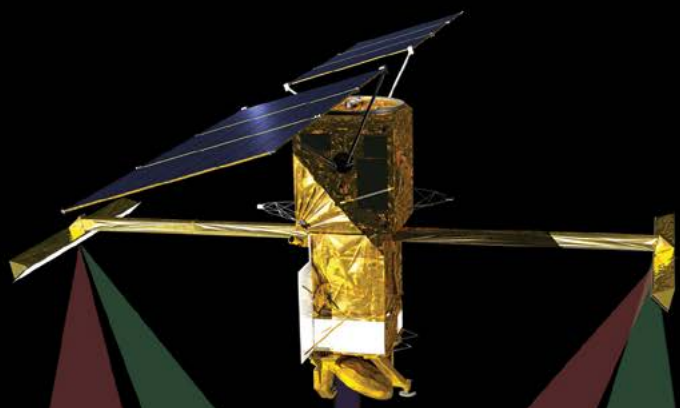
That's how far the French coastline has receded, including 270 km at an average rate of 50 cm a year.

PILOT SITE SIMULATIONS

The SWOT ST has pursued several scientific projects backed by CNES through the TOSCA Earth, oceanography, land surfaces and atmosphere programme, while NASA has lent its support to a project in the Mississippi delta (ROSES[1] programme). There are 16 pilot sites under study on either side of the Atlantic, spanning a diverse range of environments such as the St. Laurent estuary in Canada, the Senegal estuary, the Seine and Gironde estuaries and the Normandy coast in France.

Once SWOT has been launched, measurements will be acquired—in situ from boats, drones and planes—to calibrate and validate the satellite's data at several coastal sites, including in Normandy. Combined with multisource data from cameras, video and infrared drones, airborne lidar, in-situ altimeters and other imaging and altimetry satellites, SWOT will provide a multiscale vision of hydrological, meteorological and marine processes, as well as a closer understanding of coastal hydrodynamics and the morphological and sedimentary evolution of these environments. This work has also inspired a programme accredited by the Space for Climate Observatory (SCO) covering the coastline at Saint-Louis, Senegal, to preserve coastal ecosystems under threat from climate change.

1. Research Opportunities in Space and Earth Sciences.



KaRIn brings big improvements

SWOT'S REVOLUTIONARY WIDE-SWATH INTERFEROMETRIC ALTIMETRY (WIA) TECHNOLOGY IS BASED ON THE KaRIn RADAR INTERFEROMETER. This new-generation instrument has two antennas at either end of a 10-metre boom. One of the antennas emits pulses alternately to the left and right of the satellite's ground track, while return signals are received by both to form two complex images of the surface. We can then calculate the water height at each point in the image from the phase difference between the two. This process enables a swath of approximately 50 kilometres[1] to be covered on either side. Instead of sounding along track like with a nadir altimeter, we thus obtain wide-swath 3D imagery with SWOT. This technology improves data resolution and coverage and extends altimetry measurements from oceans to continental waters.

1. The two 50-kilometre swathes on either side of the ground track are 20 kilometres apart at nadir, giving a total swath of 120 kilometres.

SWOT

1

INSTRUMENTATION
AN INNOVATIVE PAYLOAD

SWOT will be carrying two altimeters: Poseidon 3, a conventional altimeter acquiring measurements directly beneath the satellite; and KaRIn, a totally new wide-swath radar interferometer (see p. 27). With its two antennas, KaRIn will scan a 120-kilometre swath. Backed by a network of 50 ground stations, the DORIS precise orbit determination system—using Doppler technologies and built by Thales Alenia Space—will provide ultra-accurate trajectory measurements.
A microwave radiometer, precision GPS receiver and laser retroreflectors make up the rest of the payload. The satellite will be capable of revisiting the same point on the globe every 21 days and will generate 3D images.

2

HYDROLOGY
RIVER STATUS REPORT

SWOT will be monitoring rivers wider than 100 metres and supplying several products:
- Reach product: for predefined 10-kilometre reaches of rivers pre-recorded in a database, SWOT will generate measurements of height, slope and width to determine discharges.
- Cycle product: a river may be observed up to four times over each 21-day cycle. For each river section, the 'cycle' product compiles all data—height, width, slope and discharge—collected over the full cycle.

AFFORDING NEW TECHNOLOGY, NEW DATA AND NEW PRODUCTS, SWOT IS THE FIRST MISSION DEDICATED TO THE GLOBE'S SURFACE WATERS. IT WILL ALSO BE SURVEYING THE OCEANS AND COASTAL WATERS. HERE ARE SOME OF THE FUTURE APPLICATIONS IT'S SET TO SERVE.

3

WATER STOCKS
SURVEYING LAKES

SWOT will observe lakes, wetlands and reservoirs with an extent of 250 metres by 250 metres. Ultimately, it aims to get down to 100 metres by 100 metres.
A single-pass product will provide measurements of surface area, water height and water stock variations. Users with bathymetry data charting a lake's bottom topography will be able to deduce the absolute value of water stocks and their variations.
A lake may be observed only partially during a pass, in which case any gaps will be filled on the next pass to obtain a 'cycle average' product providing the height and mean extent over the 21-day cycle.

4

OCEANOGRAPHY
A NEW APPROACH TO OCEANS

Over the oceans, SWOT will be pursuing the missions of its oceanography satellite predecessors, acquiring mesoscale and sub-mesoscale measurements of mechanisms whose role is still poorly understood. With bi-directional vision and ten times better resolution, it will generate data products at a resolution of two kilometres by two kilometres over a 60-kilometre swath. Expert products will also be extracted with a resolution of 500 metres by 500 metres and delivered with metadata (geographic information, instrument biases, geophysical and weather data, etc.) for processing.

KAREN ST. GERMAIN

NASA Earth Science Division Director

"NASA and CNES's partnership is so much more than the sum of our expertise."

In 1665, a French soldier by the name of St. Germain arrived in New France from his home town in Dordogne. Nine generations later, his descendant, Karen St. Germain, heads NASA's Earth Science Division and is enjoying working with the French space agency. **"Our two agencies complement each other and share the pursuit of excellence and the commitment of their people,"** she says, underlining the ties the two teams have **forged over the last 30 years.** Her passion for space grew out of her interest in the environment. When still a student, she flew through hurricanes and tropical storms on airplanes operated by the National Oceanic & Atmospheric Administration (NOAA) to study ocean winds. In 1992, for the launch of **TOPEX/Poseidon, the first French-U.S. satellite altimetry mission,** she was involved in calibrating the instruments from Norfolk Island in the Pacific. "Thirty years on, CNES and NASA are poised with SWOT to launch a new mission that's going to change how we see our planet forever. We're going to get **ten times better resolution than with current technologies to measure sea-surface height and understand the ocean fronts and eddies that help shape climate.** And we're going to improve our models and forecasting capabilities," she enthuses. As someone who has enjoyed problem-solving since she was a kid, **climate change offers a real challenge.** "I want to help devise solutions. The decisions we make must be grounded in science," she affirms. While she is eagerly anticipating SWOT's launch, NASA's Earth Science Division Director hasn't forgotten the other French-U.S. missions like CALIPSO, which for 15 years has been observing clouds and aerosols. "The signature in Washington D.C. of the Artemis Accords by Philippe Baptiste on the day of CNES's 60th anniversary shows that our two nations share the same vision that will continue guiding space exploration," she concludes.

GUILLAUME CHOISY

Director of the Adour-Garonne water board

"The water shortfall in the Adour-Garonne catchment basin will equate to over half of current annual consumption..."

France has six water boards, all guided by a key principle: water pays for water. "We take payments from those who use water or alter its quality—households, local authorities, industry, farms, etc.—and redistribute that income to local stakeholders," explains Guillaume Choisy, Director of the Adour-Garonne water board. "This money funds efforts to protect aquatic environments and helps the areas under our responsibility adapt to climate change." No mean feat when you cover **26 departments** across the Nouvelle-Aquitaine region, Occitanie and part of Auvergne-Rhône-Alpes, with widely varying geographic and socio-economic conditions. **"But all are affected by climate disruption,** and the outlook isn't good." By 2050, the water shortfall could reach 1.2 billion m^3 a year for the catchment as a whole, which is more than half of current consumption. The causes are well known: faster evapotranspiration, shorter rainy periods and groundwater "locked in" by dry soils. In response, the water board adopted a new master plan last year for water planning and management. It's also seeking to better understand the issues—which is where satellites come in. "We're already using remote sensing to calibrate water volumes in reservoirs. And **with SWOT, we'll have a better grasp of lake and river level variations.** Going forward, we'll also be relying on satellites to observe cyanobacteria and detect various types of molecules in rivers." All this valuable data is translated into action as quickly as possible. **"We'll soon be receiving twice-daily imagery that will help us determine the amount of water reserves in the ground.** We'll pass on this information to farmers, who can then adjust and target their irrigation efforts according to actual needs."

JEAN-BAPTISTE VOISIN

Managing Director of CLS Indonesia

"Satellite transmitters are helping us track plastic waste at sea..."

Jean-Baptiste Voisin's love affair with satellites began more than 20 years ago at the ISAE Supaero engineering school. But when he finished his end-of-study project at Astrium, he flew to Indonesia for a collaboration in telecommunications. Out went satellites. "15 years later, I applied to CLS and the flame was rekindled. In 2017, I became Managing Director of the Indonesian branch." The historic operator of the Argos network had been in Indonesia since 2004 and was running a number of projects with the government, such as tracking of illegal fishing, biodiversity monitoring and marine meteorology. The CNES subsidiary then added a new string to its bow with monitoring of plastic pollution. **"Indonesia is the world's second-largest plastic polluter,** and I have vivid memories of the floating carpet of rubbish on the rivers a decade ago." **The government has committed to a 70% reduction in pollution by 2025,** with measures to eradicate the problem at source and prevent dumping at sea, but waste is difficult to locate. The solution is also provided by Argos transmitters. **"Since 2020, we've released 70 transmitters into several rivers around the country to track their paths as they drift,** on the assumption they behave a lot like plastic waste. By running simulations combining this tracking data with a particle drift model, we can decide on corrective actions, installation of floating dams and collection campaigns." New developments are planned for the months ahead: a partnership with Sea-Cleaners, similar initiatives in other countries and more transmitters. "At the same time, we're continuing to refine our modelling tools, which are also used to monitor marine meteorology equipment and sargassum pollution. **The future SWOT mission promises great advances in our understanding of the oceans, such as the study of coastal eddies,** which are a real conundrum for oceanographers," concludes Jean-Baptiste Voisin.

Jacques Arnould, science historian and theologian, CNES ethics officer.

ETHICS CORNER

JACQUES **ARNOULD**

GUARDIANS OF THE WATERS

***"The Earth is blue like an orange"*: when French surrealist poet Paul Éluard coined this poetic phrase in 1929 to celebrate his love for the beautiful Gala, little did he know a century later our planet would be the focus of such anxious attention.**

Long before we could send probes into space to track the tiniest drop of water, or the faintest evidence of water's action on a planet, we developed the theory—indeed the conviction—that the presence of H_2O would be both a clue to and a precondition of lifeforms, present or past. The "affair" of the canals on Mars, which sparked much debate in the astronomy community in the late 19th and early 20th centuries, and which long influenced public opinion, is a famous illustration. Robotic exploration of the red planet and solar system and the search for new exoplanets continue to put water at the centre of many space missions.

It may not be the only explanation, but this fascination with the waters of the heavens—or extraterrestrial water—has undoubtedly prompted us to pay more attention to the water here on Earth. Like the lover-poet, but with the eyes of an astronomer, we've understood just how much our blue planet is unique in its small corner of the cosmos. We've even measured the total amount of water on Earth, which gives our planet its particular colour. If it was put into a sphere, it would be 1,385 kilometres across (about 860 miles). In other words, all of Earth's water—oceans, icecaps, glaciers, lakes, rivers, groundwater and in the atmosphere—only forms a drop, albeit a large one, compared to the diameter of Earth.

SHARED HERITAGE

So, we find ourselves in somewhat of a quandary. Space law invites us to respect the principle that celestial bodies and their resources—water in particular... where it exists—belong to the "common heritage of humankind". We mustn't claim ownership; rather, we must take responsibility and care for these resources. This is the legal status of the waters of the heavens. And what of the status of the waters of Earth, which do exist? As space technology continues to give us closer insights into its quantities and locations, its dynamics and futures, what are we doing to ensure it really is the common heritage of all? We're not the masters of the waters of the heavens, or the waters of Earth. But we must act as their kind and caring guardians.

ARGONAUTICA SESSIONS

WATER, THE COMMON DENOMINATOR

In late May, Montpellier hosted the Argonautica sessions. The Argonautica educational programme designed by CNES for young people began under the auspices of the Vendée Globe solo round-the-world yacht race 20 years ago. Today, three projects are on offer, each with water as the common denominator. Primary and secondary school pupils use data from environment-monitoring satellites to study marine biodiversity (ArgoNimaux), oceanography (ArgOcean) and the impact of climate change on water resources (ArgoHydro). Each year, participating classes attend one-day seminars at national level to share their experiences, with workshops, project presentations and the chance to meet scientists. In May, 17 fifth-grade classes met in Montpellier.

LEARN MORE:
HTTPS://ENSEIGNANTS-MEDIATEURS.CNES.FR/FR

10,000

The 9th World Water Forum,
22–27 March 2022, was attended by almost 10,000 people. The WWF takes place every three years. The first was in Marrakesh, Morocco, in March 1997.

RÉGL'EAU

AN EXPERIMENT... MADE TO MEASURE

In connection with the OECS project (see p. 10), Régl'eau is a resource for teachers involved in ArgoHydro. The exercise is simple and based on educational, scientific and community-oriented action: students install a staff gauge—like an oversized ruler—at a lake or river near their school and regularly read the water level. CNES provides the gauge and two display panels explaining the project. Pupils measure seasonal variations at a location, compare different locations on the same river and/or compare different rivers. The data is then centralized at oecsmap.org.

20

OECS gauges are in place.
Added to these are 16 LOCSS gauges (provided by NASA) and more than 10 automatic micro-stations. The project began in September 2020 and will run for three years.

ARGOHYDRO

Adour-Garonne catchment basin: pilot site

The ArgoHydro project was launched ahead of the SWOT mission with the support of CNES, which is providing the methodology and resources, and focuses on the Adour-Garonne catchment basin. Pupils and teachers are learning how to use a laser rangefinder to measure surface water levels, build a hydrology measuring buoy and collect data on temperature, pH (water acidity) and nitrate levels. Designed for younger pupils, this experiment-based project helps raise awareness about environmental issues and how to protect water as a valuable resource.

WORLD WATER FORUM

A PLEA FOR PEACE AND DEVELOPMENT

For the first time, Sub-Saharan Africa, a region severely affected by drought, has hosted the World Water Forum (WWF). The ninth WWF took place in Dakar, Senegal, in March on the theme of "Water security for peace and development". Water resources were discussed from an economic and social standpoint. The management of cross-border catchments and conflicts of interest between neighbouring countries is a major issue. Space hydrology offers the necessary perspective, with objective maps and data that transcend political borders. Partners in a working group since 2014, CNES, the OiEau International Office for Water (IOW) and the IRD sustainable development research institute emphasized the potential of SWOT for hydrology. Thanks to a project in the Congo Basin, the world's second-largest river basin, solutions have been found to help manage this river, which are now being implemented under an agreement signed by seven public- and private-sector institutions. This project was certified by the WWF as part of "Initiative Dakar 2021". With the support of the French development agency AFD, the Niger, Senegal and other rivers are set to benefit from space hydrology. This is a necessary part of the Dakar Declaration, or "Blue Deal", announced at the close of the forum, which reaffirms the urgent need for a "shared vision of a world in which every person has access to safe drinking water and sanitation".

DIARY

4-6 JUNE 2022
PARIS
SWOT Application – 2022 SWOT Early Adopter Virtual Hackathon

19-24 JUNE 2022
SAN JUAN – PUERTO RICO
AGU – Frontiers in hydrology

12-16 DECEMBER 2022
CHICAGO
AGU Fall Meeting 2022

COP27 SHARM EL-SHEIKH EGYPT 2022

COP27 UNDER THE BANNER OF CLIMATE EMERGENCY

The COP 27[1] international conference will take place in Sharm el-Sheikh, Egypt, 7-18 November 2022. More than ever, after the sixth alarming IPCC report, the signatory countries of the United Nations Framework Convention on Climate Change (UNFCCC) will have to show realism and commit to significant actions for the future. Five years after the Marrakesh Conference, the COP is back in Africa—a continent where water is a highly sensitive issue. Mohamed Abdel Aty, Egypt's Minister for Water Resources and Irrigation, said COP 27 will be a "golden opportunity to present the challenges faced by the African continent around water".

1. Conference of the Parties.

VORTEX.IO SOUNDS SURFACE WATERS

VorteX.io has developed a solution for monitoring water courses. The start-up is working with CNES on the inland hydrology part of the SWOT mission.

In January 2022, the River Garonne bursts its banks and 65 municipalities are declared natural-disaster areas. While France's major water courses are kept under close watch through the government's Vigicrues flood-alerting service, "small tributaries are increasingly a factor in flood risks and go unobserved," warns oceanographer Guillaume Valladeau. In 2018, with business partner Jean-Christophe Poisson, he took up the challenge of miniaturizing satellite altimetry instruments used to measure sea level. Their goal was to bridge the gap between space and inland hydrology. They would achieve this with a 17-centimetre instrument that can be deployed on a drone to study lakes and rivers, designed to complement SWOT satellite data. The innovation caught CNES's eye and a support contract was signed after assisting with in-flight trials.

REAL-TIME MEASUREMENTS

In 2019, the two engineers founded vorteX.io and devised a fixed, light and compact remote-sensing micro-station for monitoring water courses, anticipating floods and alerting populations at risk. A sensor acquires measurements of water height in real time with near-centimetre accuracy. "A station will detect the arrival of a flood wave upstream and alert the network," explains Guillaume. And a satellite connection will soon back up data transmission even when there's no 4G signal. "In-situ data collected by vorteX.io's sensors are used to calibrate and validate satellite measurements," notes Nicolas Picot, CNES project leader. "This is a key step in demonstrating SWOT's precision."

400

Mass
in grams of a vorteX.io micro-station.