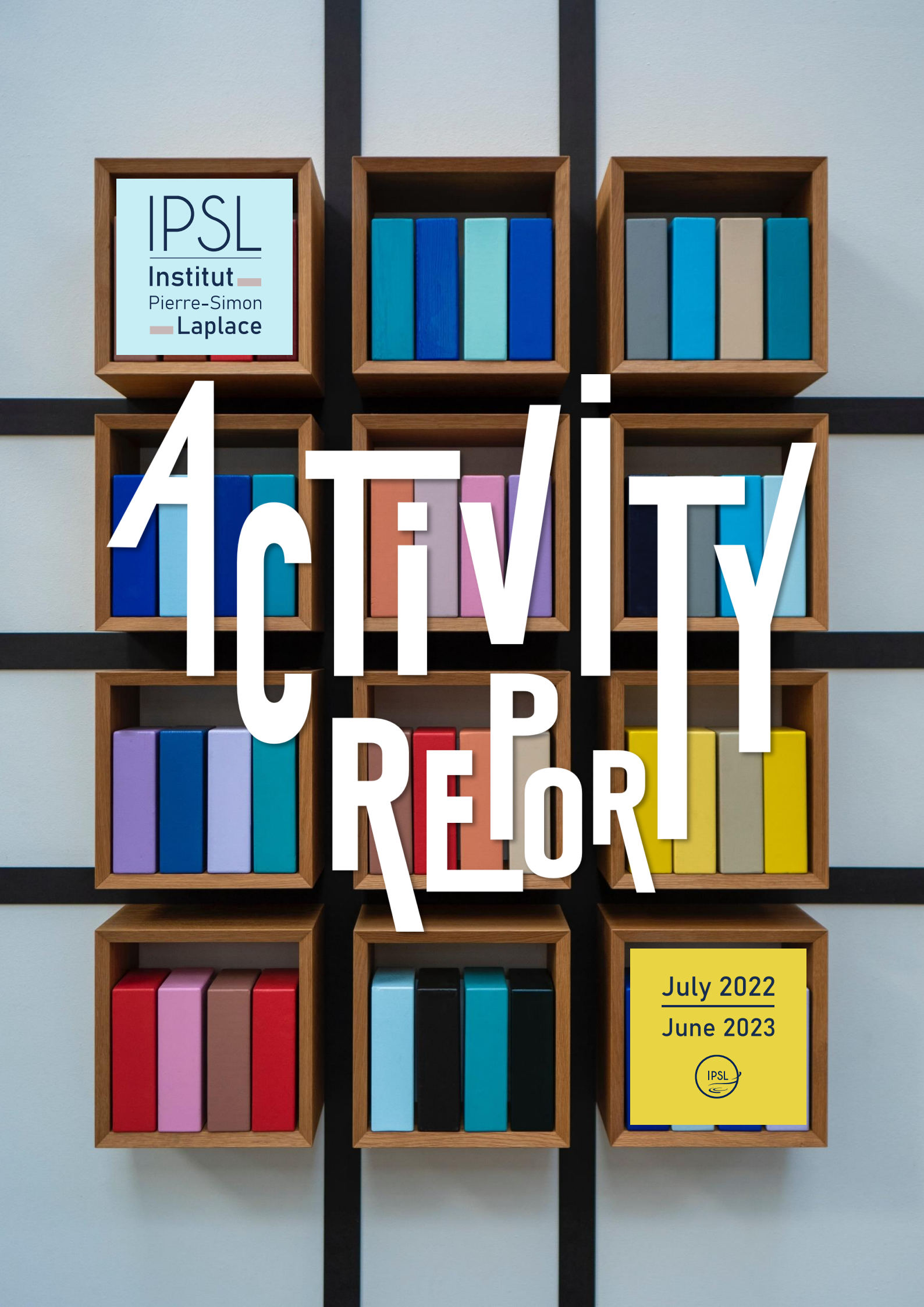

IPSL
Institut
Pierre-Simon
Laplace
ACTIVITY
REPORT
July 2022
June 2023
IPSL

Executive Summary

The Institut Pierre-Simon Laplace (IPSL) is a large research federation bringing together the experts in natural climate science in the Greater Paris area. The IPSL provides coordination, services, and access to a large, multi-disciplinary pool of expertise to the research units to tackle environmental questions from the most fundamental aspects to applications. After a short review of IPSL missions and organization, key figures, this document reports the activities that took place in 2022-2023. This year, a focus is put in particular on the research and training program, the climate services.

During the last year, nine research themes have developed a number of original activities, from basic research on paleoclimate biogeochemisty, current climate evolutions in extremes, dynamical, hydrological, chemical and biogeochemical processes, the emerging fields of climate genomics, AI for climate research, urban climate, and solar systems. Research was supported mostly by the funding of the IPSL-Climate Graduate School (École Universitaire de Recherche). In 2022, the IPSL-CGS has allowed the funding of 21 traineeships, 11 Early Career Scientists (PhD, Post-doc, researchers), 4 research engineers, 6 engineers and 3 technicians to support research and training activities as well as 12 conferences and the invitation of 5 international scientists or experts (Bernd Kärcher, Dim Coumou, Stuart Piketh, Thomas Reischler and Anna Sorensson).

Beyond research, Climate Services developed new partnerships and projects, among which a “regional science-society” group (GREC) with focus on the Île-de-France Region and the City of Paris, established a long-term partnership with the national transmission operator RTE-France, and developed research on the impact of aviation on climate. The centres and services continued their structuring activities. The communication team has developed a portfolio of communication and mediation elements on climate science questions and climate change, in various formats.

Training and education activities continued with several developments in the federation of masters in Île-de-France, and the International Virtual School, with a focus this year on the water cycle.

Table of contents


IPSL
objectives
and
activities
1

The “Institut Pierre-Simon Laplace” (IPSL) is a Federation of 8 research units and 2 associated teams in the Paris region. Its main objectives are to facilitate research and training coordination, develop innovative research and training programs and deliver common services across activities of its member research units with a focus on climate sciences.

The 8 laboratories are CEREA[1], GEOPS[2], LATMOS[3], LISA[4], LMD[5], LOCEAN[6], LSCE[7] and METIS[8] and 2 more teams, belonging to LERMA[9] and the ENS department of Geosciences[10]. The IPSL coordination and service teams host 78 staff, 40 of which are permanent and about 38 are on fixed-term contracts. In total, IPSL brings together about 1500 staff in the greater Paris region, working on natural science of climate and environment.

IPSL is funded by its founding research organizations and universities, as well as by funding research agencies or ministries, European projects, and industrial contracts. In particular it is largely supported by the “École Universitaire de Recherche” IPSL-Climate Graduate School (IPSL-CGS), a 10-year education and research programme on climate change.

[1] Centre d’Enseignement et de Recherche en Environnement Atmosphérique
[2] Geosciences Paris-Saclay
[3] Laboratoire Atmosphère, Observations Spatiales
[4] Laboratoire Inter-universitaire des Systèmes Atmosphériques
[5] Laboratoire de Météorologie Dynamique
[6] Laboratoire d’Océanographie et du Climat, Expérimentations et Approches Numériques
[7] Laboratoire des Sciences du Climat et de l’Environnement
[8] Milieux environnementaux, transferts et interactions dans les hydrosystèmes et les sols
[9] LERMA, TASQ team
[10] Laboratoire de Géologie de l’ENS, “Surface et réservoirs” team

IPSL overarching goals

As agreed with its governing organizations, IPSL has seven major objectives:

1. Research. Develop and coordinate an innovative and cross-cutting research programme on the climate of the Earth and other planets, and its interactions with the environment and climate change.

2. Training. Coordinate, in conjunction with the parent universities and research organizations, a coherent training offer on climate and climate change for students and professionals, and develop international partnerships.

3. Modelling. Coordinate the development of IPSL climate models, in particular global, regional, and Earth system configurations, as well as their applications for the study of past, present and future climates, as well as the development of climate models for other planets.

4. Observation. Coordinate the discussion of laboratories and observatories on observations, in particular on long series of measurements and major campaigns, and lead a strategic reflection on scientific and technical activities around space missions for the study of the climate, and on instrumental development.

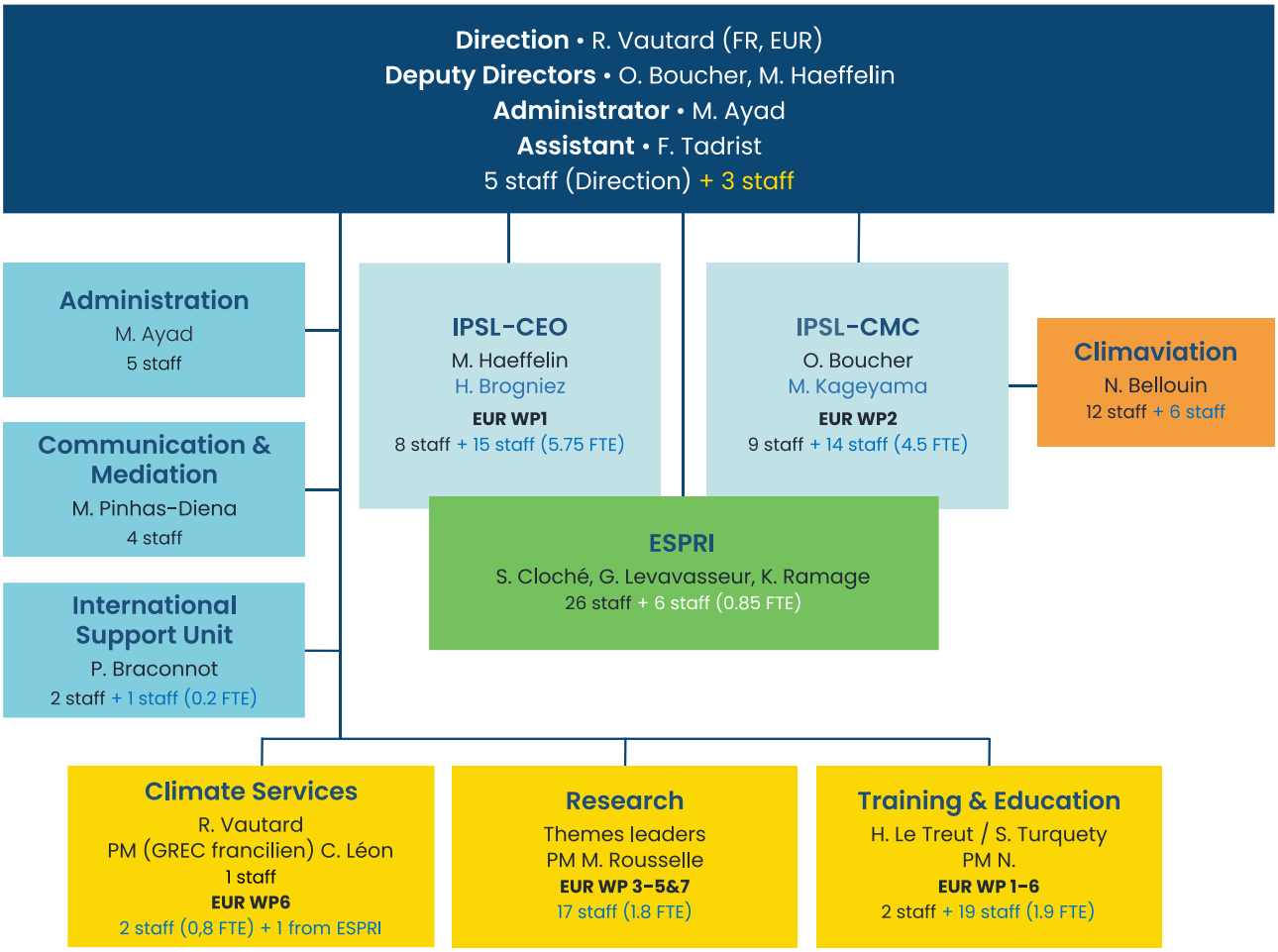
5. Data and computing. Develop and offer a set of regional, national and international IT services for research related to computing, storage and use of environmental and climatic data.

6. Communication and mediation. Define and deploy a communication action strategy (institutional, internal, external and digital) and mediation to promote, at national and international levels, IPSL scientific activities; set up an agile communication strategy in partnership with the supervisory authorities; design and organize operations and events to mediate between science and society and produce resources for a large and diverse audience.

7. Climate services. Develop and promote the emergence of science-society links on climate change through interdisciplinary scientific projects, establish climate services as a new scientific issue, in conjunction with stakeholders, and develop the emergence of applications of climate research outside the academic sector in the field of climate change.

IPSL organization and activities

IPSL activities are organized along the major goals, as represented in figure below: Research, Training & education, IPSL Climate Modeling Center, IPSL Earth Observation Center, ESPRI services, Communication and Mediation, Climate services and the International support unit. In each activity, staff from the coordination and services or from research units are leading and developing the activities.



A total of **78 staff (77.5 FTE) within FR IPSL** and **74 staff (15.6 FTE) outside FR IPSL** (2023).

Organization of IPSL activities, and main responsible persons and project/programme managers.

The main IPSL activities, which are grouped into centers, services and programme coordination and management:

The **research program** provides scientific coordination and resources along 9 strategic research themes that necessitates bringing together teams from several research units. In addition to the research coordinated within each scientific theme, IPSL runs a support scheme for workshops, a visiting scientist programme, and an internal call for innovative research.

The **training and education program** is designed to tackle climate challenges to be faced in the coming decades, which requires the training of a new generation of societal relays for the understanding of the challenges in the population and among decision-makers. It supports an array of training projects and master and PhD level.

The **IPSL Climate Modelling Center (IPSL-CMC)** is responsible for the development of an Earth system model through the integration of its major components, the realization of climate simulations and the distribution of their resulting datasets, the analysis of past, current and future climate variability and changes, and the development of modeling techniques.

The **IPSL Earth Observation Center (IPSL-CEO)** facilitates the IPSL coordination for satellite missions to support on-going missions and new space concepts, supports coordinated actions for long-term monitoring such as in the ACTRIS or ICOS research infrastructures, supports the maintenance of long-term datasets and data management from multiple instruments, as well as instrumental platforms and instrumental development. In particular, IPSL operates a world-class atmospheric observatory (SIRTA multi-instrument supersite located on the Saclay Plateau) for cloud, aerosol, trace gas and renewable energy research.

The **ESPRI computing and data services** are in charge of system and network administration and the life-cycle of data from the IPSL Climate Modeling Center (CMC) and Centre for Earth Observation (CEO). They cover various fields such as data acquisition or production, data archiving and distribution and support of multidisciplinary projects carried out at IPSL.

The **Communication and mediation Department (ICOM)** defines and implements a strategy of communication actions (institutional, internal and external) and mediation.

The **Climate Services** activity develops data and projects with several stakeholders in order to transfer climate change knowledge to decision makers. Beyond offering data access and computing, IPSL co-develops climate services projects and new methodologies to adapt model and observed data to user needs, and an interface with regional policy makers (GREC francilien). Climate services are currently shared between ESPRI and a group of other scientists and project managers.

The **International Support Unit (ISU)** provides a link between the national climate community and international flagship programmes in the field of Climate Change (WCRP – World Climate Research Programme) and Global Change.

The administration service provides key administrative and management support for the programs, centres and services.

IPSL in numbers

2

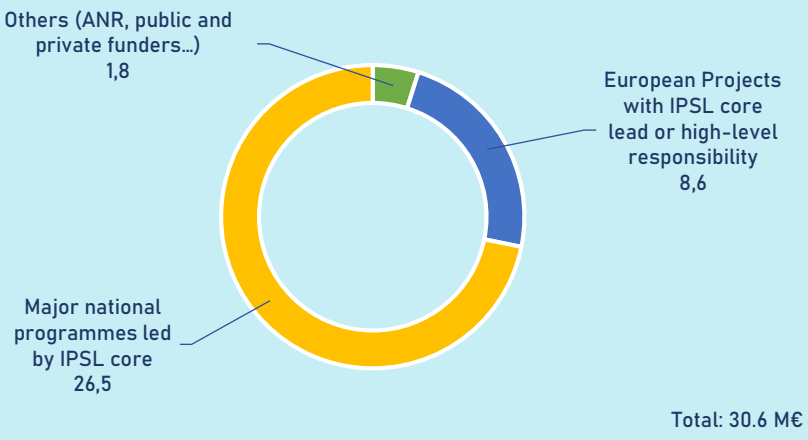
IPSL includes about 1500 staff. IPSL has a number of leading scientists in climate sciences, reflected by **8 scientists involved in the 6th IPCC cycle**. Valérie Masson-Delmotte (LSCE-IPSL) is one of the two co-chairs of the WGI, Sophie Szopa (LSCE-IPSL) and Robert Vautard (IPSL) are AR6 WGI Coordinating Lead Authors, Jean-Louis Dufresne (LMD-IPSL), Jean-Baptiste Sallée (LOCEAN-IPSL) are AR6 WGI Lead Authors, Laurent Bopp (LMD-IPSL) is AR6 WGII Lead Author, Nathalie de Noblet is Lead Author of the Special Report on Climate Change and Land and Pascale Braconnot is Review Editor of the WGI report.
https://www.ipsl.fr/article/regards-intimes-sur-le-giec/

IPSL also recognized in national academies in climate and planetology (**5 members of the National Science Academy**, Philippe Ciais (LSCE-IPSL), Jean-Claude Duplessy (LSCE-IPSL), François Forget (LMD-IPSL), Jean Jouzel (LSCE-IPSL), Hervé Le Treut (IPSL), **1 member of the National Agriculture Academy** (Nathalie de Noblet, LSCE-IPSL), **1 member of the China Academy of Science** (Philippe Ciais, LSCE-IPSL).

Projects

IPSL leads or manages large projects involving teams from several IPSL research units and requiring coordination (at national and international level):

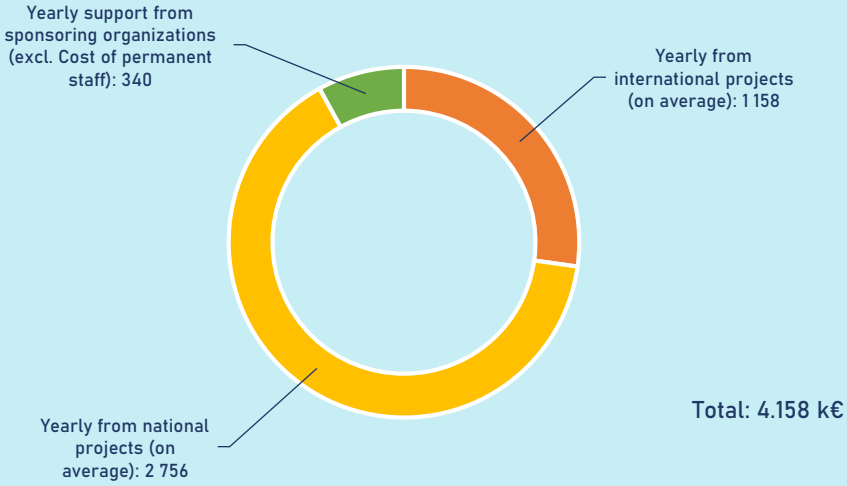
- 18 European projects with lead or high-level responsibility;
- 3 major national programmes led by IPSL core team (EUR IPSL-CGS, CLIMAVIATION and PEPR TRACCS);
- 21 other projects (ANR, public and private funders...).



Total multi-year budget of projects managed by FR IPSL (M€).
This does not include the budgets managed by individual research units.

Annual Budget (2022, k€)

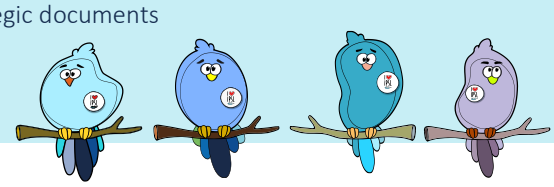
- 340 k€ yearly support from sponsoring organizations
- (excl. cost of permanent staff);
- 3.914 k€ yearly from all projects (on average);
- 2.756 k€ year from national projects (on average);
- 1.158 k€ year from international projects (on average).



Total: 4.158 k€

Communication and mediation

- **1 website** (FR & ENG) **300+** online news, **150+** seminars/webinars announcements
- Social media: (followers) Twitter **3200+**, LinkedIn **+1800**, Facebook: 6100+, Instagram: **675+** followers; YouTube: **~700 followers**, **150+** videos
- 1 podcast "Le climat, une question de…" **11 issues**, **+830 dowloads**
- **30** Videos, teasers & animations (for social media)
- **5** Mediation events
- **10+** Mediation and strategic documents
- **1 mascot, "The SPILOU"**



The IPSL – Climate Graduate School: the EUR program

The EUR (standing for École Universitaire de Recherche or "university research school") is a major programme funded under the "Programme d'Investissements d'Avenir" by the National Research Agency (ANR). As its name suggests, it is mainly focused on the issue of university training through research.

IPSL benefits from such a grant for 10 years (2018-2028), called the **IPSL-Climate Graduate School (IPSL-CGS)** program. This program is divided between two components of equal importance, and of expected mutual benefits: Training and Research. The total grant is 14 million euros spread over 10 years. In 2022, 850 k€ were dedicated to training and education while 1,120 Million were dedicated to Research.

The objectives of IPSL-CGS is to develop a world-class program for research and training on issues related to the climate system, climate change and their impacts rooted in the large expertise of the IPSL scientific community in the Île-de-France Region. It also aims at making climate research and education visible and attractive at national and international level, and to support mutualisations across partner universities and research organizations. The EUR IPSL-CGS is supporting the IPSL centers, the climate services activity, and other scientific activities (all research themes below but the "solar systems" theme).

The program is supporting 6 training types of activities, with the goal of strengthening climate education at Master degree level, and transitioning from Master to PhD. It also supports the funding of 4 new PhD students each year. An international virtual school is organized each year, as well as several student's workshops. It also supports innovative communication and mediation activities.

Overall, the IPSL-CSG program is the main source of incitative and flexible funding which allows IPSL direction to develop a scientific policy, with the goal of training new generations of students and researchers to climate change challenges.

3

The research program, which benefits from a ~1 M€/Year, mostly from the IPSL-CGS government program, is designed to foster collaborations across IPSL laboratories on key scientific themes, and to provide an attractive framework for master students to be trained from research activities. It is also a seeding program to initiate new ideas and strengthen teams with engineering support in order to help them achieve ambitious goals.

We detail here the goal and achievements of each research theme, and the climate service activity which includes a number of innovative developments close to research.

Research themes

- Understanding past climate evolution, variability and its impact on the environment
- Internal and forced climate variability
- Water Cycle
- Land biogeochemistry, Ecosystems and Agriculture (BIOTECA)
- Marine biogeochemistry, ecology, and resources
- Atmospheric composition and air quality (Composair)
- Solar Systems
- Statistics for Analysis, Modeling and Assimilation (SAMA)
- Urban Environment – Cross-cutting theme
- IPSL Climate services

Understanding past climate evolution, variability and its impact on the environment

Theme leaders
Aline Govin (LSCE-IPSL) · Charlotte Skonieczny (GEOPS-IPSL)

The theme in a nutshell

The IPSL "Paleoclimate" theme investigates the natural evolution of the Earth's climate, as well as the related mechanisms and environmental responses over time periods ranging from the Earth's geologic past (million-year to (sub)orbital time scales) to recent (millennial to decadal variability). The theme involves around 35 active scientists from five IPSL research institutes (GEOPS, LMD, LOCEAN, LSCE, METIS), while about 100 IPSL scientists subscribed to the internal mailing list.

Major tools. We have, within the theme, exceptional tools at our disposal:

- State-of-the-art analytical facilities for the dating and reconstruction of multiple climate variables from various archives;
- Rich multi-archive data bases and unique tools to integrate the chronologies of climatic archives;
- A whole range of Earth climate models (from conceptual to fully coupled models) allowing experiments on all time scales, and the direct simulation of tracers (e.g. geochemical and isotopic tracers, bio-indicators).

Our analytical facilities belong to mostly four analytical platforms shared between IPSL institutes. Developments and simulations of the IPSL Earth System model are done as part of the IPSL Climate Modeling Center. This rare model-data ecosystem facilitates interdisciplinary research activities, in a quasi-unique manner at the national and international level.

Major projects. The group is currently leader of and involved in several international and European projects (e.g. Belmont Forum, European Research Council, International Research Project). It leads numerous national scientific projects, in collaboration with the French paleoclimate community outside the Paris Region. IPSL paleoscientists have a leading role within renown international programs such as the Future-Earth global research project "Past Global Changes" (PAGES), GEOTRACES ("An International Study of the Marine Biogeochemical Cycles of Trace Elements and Isotopes"), and the Paleoclimate Modeling Intercomparison Project (PMIP). Partnerships with the South are particularly active through the French National Research Institute for Sustainable Development (IRD) and its abroad international laboratories.

Recent advances. The IPSL paleoclimate community highly contributed to recent scientific advances such as the European Project "Beyond EPICA" that aims to drill and study 1.5-million-year-old Antarctic ice, or the new exercise assessing model performances as part of Model Intercomparison Projects (e.g. PMIP4, Ice Sheet MIP6).

Opportunities and limitations. Paleoclimate activities are in particular limited by the difficulty to renew aging instruments within analytical facilities, as well as the overall progressive loss of technical and scientific expertise for both analytical and modeling

aspects. However, the white paper on paleoclimate studies in France (to which the IPSL paleoclimate community strongly contributes) will be published this year and hopefully provide new funding and hiring opportunities in the future.

Summary of activities in the last 5 years. The "Paleoclimate" group has two major research aims: (1) determine mechanisms controlling the natural variability of the Earth's climate across time scales, and (2) develop simple tools to search through, process and compare experimental paleo-data and climate model outputs. The main achievements of the theme can be summarized as follows.

1. Regular meetings strengthened existing links and initiated new collaborative projects around two federative topics (Southern Ocean teleconnections and Monsoonal systems). Joint supervision of master internships initiated new synergies and led to regionally-funded projects (IPSL, Paris-Saclay) and a national project (ANR BIOCOD).
2. In collaboration with the IPSL Center for Earth Observations and ESPRI, two international databases have been developed for the perennial archiving of paleo-data using the international Linked PaleoData standardized format.
3. The group designed an easy-to-use and adaptive tool facilitating model-data comparisons for non-experts based on Jupyter notebooks (https://tinyurl.com/nrh5wkhu) and organized training workshops.
4. The group initiated the ongoing upgrade of the now obsolete *Analyseries* software, internationally run with success for 30 years.
5. The group initiated, in collaboration with other IPSL themes and the IPSL Climate Modeling Center, the ongoing perennial implementation of water stable isotopes in all components of the IPSL Earth System Model.

The paleoclimate group also contributed to:

- student's training activities via master internships, projects for engineering schools, the organization of JupyterLab and Python workshops for PhD students and scientists, and teaching involvment in Bachelor and Master degrees of Paris region.
- IPSL communication activities through the 30 years of the PMIP program in 2022, a TV documentary (Ushuaia Nature), the annual "Fête de la Science", workshops on Climate and Paleoclimate in schools of Paris region and museums (e.g., Cité des Enfants). Websites focused on climate and paleoclimate topics have been designed: e.g. an interactive webpage explaining the measurements made on Amsterdam Island by the IPSL members (https://ile-aux-mesures.institut-polaire.fr/) and a webpage following an oceanographic cruise involving numerous IPSL paleoclimate scientists: www.amaryllis.ipsl.fr

Main orientations. Our aims for the next five years remain twofold. First, we plan to further develop collaborative projects around our two federative topics and open discussions on new emerging topics within the theme, with the same redline to combine paleo-data reconstructions and climate model simulations to address scientific questions. Second, we plan to further develop paleoclimate tools, with a specific focus on the perennial implementation of water stable isotopes in the IPSL Earth System Model and the upgrade of the Analyseries sotware.

Activities (2022-2023)

The main achievements of the IPSL paleoclimate group over the period of interest include the following actions:

1. The IPSL-funded postdoc position as part of the Federative project "Southern Ocean" started in April 2023. Pauline Depuydt will update an existing database of glacial biological productivity and analyze model simulations to determine the role of biological productivity changes in past atmospheric CO_2 variations.
2. The two IPSL-funded research engineer positions as part of the trans-theme "Model stable isotopes" action started early 2023. Mohamed Ayache and Aya Bahi will work on the perennial implementation of water stable isotopes in the ocean (NEMO) and land surface (ORCHIDEE) components of the IPSL model, respectively.
3. The "Monsoons" federative project re-initiated regular discussion meetings. Collaborative work as part of this project will be fostered by the ongoing AMARYLLIS-AMAGAS oceanographic cruise (see Highlight).
4. Vizualisation tools are currently under development for the international African Pollen Database available online (https://africanpollendatabase.ipsl.fr) The development of the companion IPSL Paleo Data Base is progressing, despite unexpected technical and scientific challenges.
5. The upgrade of the widely used Analyseries software slowly progresses under the format of master projects for engineer schools. Several tabs have been converted from the original C++ code to Python. Good candidates for the on-year research engineer position funded by IPSL chose other carrier pathways.
6. IPSL Paleo group members regularly contribute to communication activities such as the annual "Fête de la Science" (escape game in the LSCE core repository, discovering paleoclimate reconstructions at GEOPS through microscopic and sediment core's observations). Members of the group also contribute to the redaction of the Past Global Changes Horizons magazine that is a new publication designed for teenagers and young adults who are interested in learning more about paleoscience, past global changes, and science in general: https://pastglobalchanges.org/publications/pages-magazines/pages-horizons/129217

Highlight

The oceanographic cruise AMARYLLIS-AMAGAS is a strongly multidisciplinary and international project, which involves tens of scientists from 9 research institutes in France, 8 universities in Brazil, 2 universities in Germany and one university in Sweden.

Organized in two legs for a total duration of 49 days, this research cruise takes place on board the French research vessel Marion Dufresne, between May 16th 2023 and July 3rd 2023. The AMARYLLIS-AMAGAS campaign aims to better establish the major but uncertain role played by the Amazon region in the Earth's global climate system. It is organized around 4 scientific objectives:

1. reconstruct the climate history of the Amazon basin and NE Brazil, at various time scales of the last million years;
2. assess the modern and past contribution of Saharan dust deposited in this region, in particular its role as a fertilizer for the Amazon rainforest;
3. examine the relationship between gas hydrates and large-scale submarine landslides in the upper Amazon cone;
4. assess the extent of gas outflow to the ocean at the scale of the Amazon cone as a whole.

To meet these objectives, the AMARYLLIS-AMAGAS cruise will implement (i) the coring of sedimentary sequences at 16 stations, (ii) in situ temperature measurements of sediments at 5 stations located in gas hydrate areas, (iii) acoustic imaging of the water column, seafloor and upper sediments along 7 transects framing the Amazon cone, and (iv) observation of the atmospheric column and collection of modern atmospheric dust, continuously on board.

At the IPSL level, the AMARYLLIS-AMAGAS cruise involves about 25 students, technicians, engineers and researchers from 4 IPSL institutes (LSCE, GEOPS, LOCEAN, METIS). The material collected will provide the basis for collaborative projects investigated over the next 10 years within the IPSL Paleo group, in particular as part of the "Monsoon systems" federative project. Multiple training and communication actions are already taking place or planned. A website is under construction (https://www.amaryllis.ipsl.fr).

Main Publications (100% Open Access)

All publications relevant to the "Paleoclimate" theme are listed here:
https://lite.framacalc.org/publications-du-theme-paleo-ipsl-9tqd

Internal and forced climate variability

Theme leaders
Guillaume Gastineau (LOCEAN-IPSL) · Aurélien Podglajen (LMD-IPSL)

The theme in a nutshell

The theme focuses on understanding the variability of the climate system and its components across different timescales, ranging from the diurnal cycle to multi-centennial fluctuations. It investigates the roles of anthropogenic and natural forcings in shaping climate patterns. Additionally, the research aims to analyze and attribute hazardous and extreme weather events with significant global impacts. The research community gathers mainly four laboratories (LATMOS, LMD, LOCEAN, LSCE) and some staff from IPSL. It gathers about 50 permanent researchers (from the managed mailing list).

Major tools. The research conducted is based on various configurations of ocean, atmosphere and/or climate models. It is also conducted with observation from various origins (balloon-borne, airborne field campaigns, lidar-radar or satellites).

Major projects.

- **EUREC4A (ERC, CNRS, and international partners):** understanding of the interaction between convection and large scale circulation in the tropics, using fields campaigns and atmospheric models (www.eurec4a.eu).
- **STRATEOLE-2 (CNES):** investigations of the processes between the lower stratosphere and the troposphere in the tropical tropopause layer in tropics with CNES super pressure balloons.
- **OPTIM-ESM (H2020):** improvement of the biogeochemical, land-surface, ocean-atmosphere interaction in climate models in order to understand the tipping points.
- **EUCP (H2020):** bias correction of the climate models outputs to understand and forecast weather extremes.
- **XAIDA (H2020):** use of artificial intelligence to detect and attribute extreme weather events.
- **THINICE (CNRS, ONR, CNES):** analyses of diabatic processes in Arctic summer depressions, using satellite observations, fields campaigns and climate models.

Recent advances. IPSL has also been a leader in evaluating the response of the climate system to extreme wildfire events reaching the stratosphere, such as the 2020 Australian fires, and the large volcanic eruption of the Hunga Tonga volcano in 2022. In particular, a team from IPSL was the first to show that the Hunga Tonga volcano had the potential to warm the climate system (instead of the cooling generally expected from volcanic eruptions).

Summary of activities in the last 5 years.

- New results from the analysis of CMIP6 experiments: advances in detection-attribution, understanding of Polar-Amplification, and new insight in the decadal predictability of the North Atlantic Oscillation at the decadal time scale.
- About 15 master 1 and 2 internships financed mainly one three topics “Polar climate processes”, “Tropical climate variability” and “Understanding of extreme climate events”.

- We contribute to communication through the setting up of **ClimariQ**. ClimarisQ is an educational game that served and serves as communication tool for the IPSL (fete de la Science, Forum MeteoClimat). It aims at raising awareness and understanding of the effects of climate variability, with a focus on extreme weather events and their attribution. It allows participants to explore the impact of mitigation and adaptation choices on the climate system at local, regional, and global levels. The activity emphasizes the role of both anthropogenic and natural forcings in climate variability and encourages participants to make decisions on a continental scale to achieve a greener trajectory. The game mechanism of Climarisq allows participants to experience the effects of extreme events such as heat waves, cold waves, heavy rainfall, and drought generated by a real climate model, while balancing "popularity", "ecology", and "finance" gauges. Overall, Climarisq is a valuable communication activity for understanding the complex interactions between human activities and the climate system, as well as the need for both mitigation and adaptation strategies to address extreme weather events.

Main orientations. The theme is very large and a few topics will be selected for funding. The studies of key processes key for the climate variability will be encouraged through the support of one early career scientist from IPSL.

Activities (2022-2023)

The field campaign THINICE led to the measurement of key diabatic processes in several of low-pressure systems in the Arctic in boreal summer 2022. An outreach article was published in the journal *La météorologie* in November 2022. This project was supported by the theme with a master internship in summer 2022.

Andreia Hisi was hired as a research engineer in the UMR LSCE with a focus on automating statistical analyses for climate variability research and communication. In 2022, she presented her analysis during the General Assembly of Theme 2. Andreia has been actively working on the development and implementation of a routine on the LSCE server, which updates ERA5 data over the North Atlantic and performs attribution of the atmospheric circulation using analogues. This routine involves complex procedures including data retrieval, pre-processing, and analysis.

Through Andreia's work, significant advancements have been made in understanding the atmospheric circulation over the North Atlantic and its potential implications for weather and climate. To disseminate these findings, we have initiated outreach activities by sharing the results at conferences and publishing them in relevant scientific journals. Additionally, we plan to develop educational materials such as tutorials and webinars to facilitate the understanding and utilization of Andreia's techniques and methods by other researchers and students.

Furthermore, we aim to engage with policymakers and stakeholders to raise awareness about the potential impacts of the North Atlantic atmospheric circulation on weather and climate. By doing so, we aspire to contribute to decision-making processes regarding climate change adaptation and mitigation.

We funded two master internships. A master 2 (second year) internship aims at investigating the Peru-Chile Upwelling system and the Humboldt oceanic current in climate models and observations, under the supervision of Mathieu Carré (LOCEAN).

A master 1 (first year) internship investigates the sea surface salinity mean state and variability and in the North Atlantic Ocean, with observations and climate models, under the supervision of Juliette Mignot.

The game ClimarisQ (see above) was presented during the Fetes de la science in October 2022 in the UMR LSCE.

Highlight

A new study (Faranda *et al.*, 2023) has highlighted that human-induced climate change contributes to the occurrence of prolonged droughts such as the one that affected Western Europe and the Mediterranean region in 2022. This study investigates the impact of anthropogenic climate change on droughts by using the method of circulation analogs. By comparing droughts from periods before and after the onset of climate change (1836-1915 and 1942-2021, respectively), and excluding interannual and inter-decadal variability as possible factors, the research team was able to identify the contribution of anthropogenic climate change. The study found that the drought of 2022 was associated with a persistent anticyclonic anomaly over Western Europe. The circulation analogs from the period of 1942-2021 generally presented larger and more intense anticyclonic anomalies that caused higher surface temperatures compared to those of 1836-1915. These characteristics exacerbated the drought by increasing the affected area and intensifying soil dryness through evapotranspiration. The results of this study highlight the importance of continuing efforts to reduce greenhouse gas emissions and mitigate the effects of climate change. The role of anthropogenic climate change in exacerbating droughts has often been discussed in public debates, but this study provides evidence that supports the linkage. The study's use of circulation analogs to identify the contribution of anthropogenic climate change also aligns with the report's goal of understanding the role of anthropogenic or natural forcings in the climate system's variability.

Main Publications (100% Open Access)

- Jiang *et al.*, (2023) https://doi.org/10.1175/JCLI-D-22-0608.1
- Sellitto *et al.*, (2023) https://doi.org/10.1029/2021JD035974
- Khaykin *et al.*, (2022) https://doi.org/10.1038/s43247-022-00652-x
- Faranda *et al.*, (2023) https://doi.org/10.1088/1748-9326/acbc37

Water Cycle

Theme leaders
Ludovic Oudin (METIS-IPSL) · Victor Pellet (LERMA-IPSL) · Antoine Séjourné (GEOPS-IPSL)

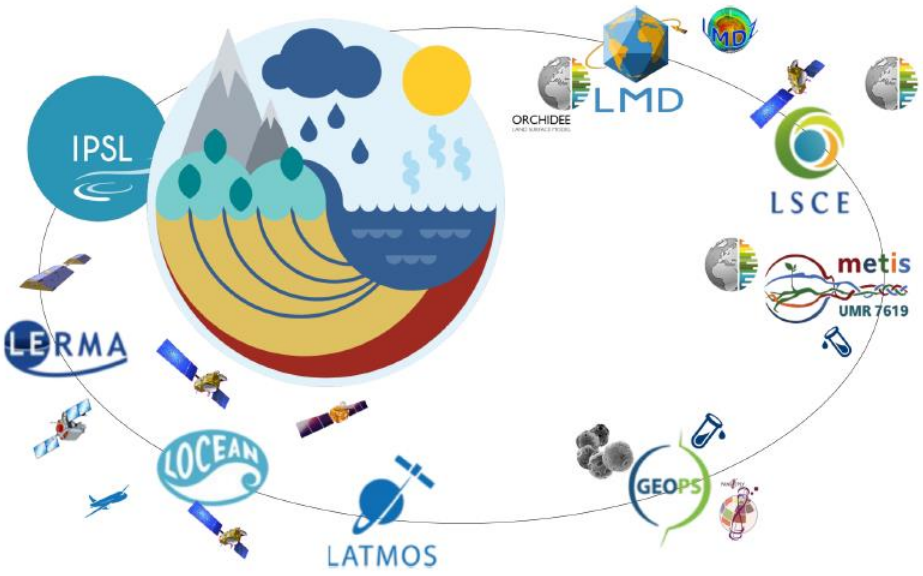
The theme in a nutshell

The Earth has a limited amount of water that is recycled in the so-called "water cycle", only a small part of which is fresh and therefore usable by humans. The interaction processes between the different components of the water cycle are still poorly understood. Climate change, weather conditions and human life are strongly affected by changes in this continuous and interconnected cycle. IPSL has all the competences needed to advance our understanding of the processes governing the water cycle within the atmospheric, continental, oceanic and cryospheric reservoirs. The aim of this theme is to strengthen the collaborations between these disciplines and thus develop an integrated perspective of the water cycle. By promoting transdisciplinary research and co-investigation projects between different IPSL members, the theme shall structure and organize research in order to reinforce an integrated vision of the water cycle in the context of Climate change and anthropogenic pressure. IPSL Water Cycle theme brings together researchers from very different backgrounds: there are among us physicists, chemists, ecologists, geologists, meteorologists, hydrologists and oceanographers. The approaches, methods of analysis and tools used are thus equally diverse and in most cases in an integrated way: observations (satellite or in situ), numerical models and experimental catchment studies are the backbones of the community. The laboratories involved are the LMD (Laboratoire de Météorologie Dynamique), the LATMOS (Laboratoire ATmosphères, Observations Spatiales), the LSCE (Laboratoire des Sciences du Climat et de l'Environnement), GEOPS (Géosciences Paris-Saclay), the METIS (Milieux Environnementaux, Transferts et Interactions dans les hydrosystèmes et les Sols), and the LOCEAN (Laboratoire d'Océanographie et du Climat). The TASQ (Télédectection, Atmosphère, Spectroscopie Quantitative) group of LERMA (Laboratoire Exploration des Radiation et de la Matière en Astrophysique et Atmosphère) complete the community. The community gathered about 30 scientists active in the theme (i.e. gathering in person in all assembly, providing scientific presentations and discussion).

Major projects. The theme benefits from several structuring projects. PIREN-Seine is a research group whose aim is to develop an overall vision of the operation of the system comprising the Seine hydrographic network, its watershed and the human society which depends on it. Members of the theme are actively involved in the Explore2 project, which aims to update knowledge on the impact of climate change on hydrology based on the latest publications of the IPCC, but also to support territorial stakeholders in understanding and using these results so that they can adapt their strategies for managing water resources.

The CNES-NASA Surface Water and Ocean Topography (SWOT) mission has just been launched last December (2022). It will provide critical information on water resources, monitor coastal processes and ocean changes. This mission will strongly benefit to the water cycle theme in both calibration of the model and observing the state of the hydrological cycle.

Summary of activity in the last 5 years. The past (2019-2022) strategy of the theme has suffered from covid pandemic as most scheduled activities scheduled were strategic brainstorming meetings. In 2021, The Water Cycle themes was divided in five sub-theme (1) Evolution of the Arctic Water Cycle, (2) Anthropogenic and climatic pressures on the continental branch of the water cycle, (3) Couplings of the Antarctic water cycle compartments, (4) Water cycle extremes: precipitation and droughts and (5) Organisation of the tropical atmosphere by oceans and land. The animation of the theme has been renewed in 2022 (with new theme leaders Ludovic Oudin, Victor Pellet and Antoine Séjourné), the community has taken the advantage to review the organization of the Water Cycle theme to initiate new synergy and encourage the emergence of new working groups. While collaboration with the theme BIOTECA is under implementation (see below), promising collaboration with the new theme Urban Hydrology is planned. Following an internship supported by the theme, a PhD has been funded by IPSL to conduct a comprehensive analysis on urban hydrology based on an integrated approach. This thesis is supervised through an inter-laboratory collaboration between LATMOS and METIS.



Activities (2022-2023)

Five inter-laboratories Master 2 internships have been selected and funded in 2023. Five or six structuring inter-laboratories projects in support of the Working Groups will be soon funded (open call ends in April, selection in May). The GIS interface of the ESPRI meta-catalog will be delivered to the community in May with a user guide to upload.

The theme is leading the scientific organization of the fourth edition of IPSL Virtual School from the Climate Graduate School (IPSL-CGS) focusing on the water cycle and related climatic issues in the framework of Climate Change. This event will be held online from Paris (France), June 26-29, 2023. The Summer school targets undergraduate and master students from around the world who are motivated by the challenges of climate sciences and wish to pursue a research career in Climate and Environmental Sciences in France. During the annual Theme workshop (1st February

2023), PhD student and post-doctoral researcher students presented their research to the IPSL water cycle community.

The use of the diffusion list theme_watercycle@listes.ipsl.fr will facilitate communication with recurrent newsletter and the deployment of collaborative Slack tools should strengthen contact and direct exchange in a simple manner. The theme is contributing to the IPSL news by submitting news about field study (Artic Antoine Séjourné) or work of researchers (Victor Pellet).

Highlight

The Water Cycle theme has enabled new research to be initiated within IPSL on the hydrological impact of urban areas. The theme had funded an M2 internship in 2021 and a thesis topic was submitted and then funded by IPSL on this subject (start of thesis October 2021). The thesis aims at conducting a comprehensive analysis on urban hydrology based on observation data analysis and the development of a dedicated modeling. The first objective of the thesis is to quantify from observations the impact of urbanization on flow rates and in feedback on precipitation. This feedback effect (amplification of precipitation over and downwind of cities) is likely to exacerbate the harmful effects of soil sealing on urban flooding but is poorly studied. To specifically evaluate the effects of soil sealing and increased precipitation, the doctoral student will develop a specific urban module in the ORCHIDEE model. A first article is being published on a critical literature review of the effect of the city on precipitation. This thesis also contributes to the emergence of the cross-cutting theme on urban environments within EUR.

Main Publications (100% Open Access)

- Lalonde-Le Pajolec, M., Dulac, A., Bastin, S., and Oudin, L.: Impact of urbanization on precipitation: a multi-site observation and modelling approach over the United States of America., IAHS-AISH Scientific Assembly 2022, Montpellier, France, 29 May–3 Jun 2022, IAHS2022-34, https://doi.org/10.5194/iahs2022-34, 2022.
- Ludovic Oudin; Morgane Lalonde. Pitfalls of space-time trading when parametrizing a land use dependent hydrological model. Comptes Rendus. Géoscience, Online first (2023), pp. 1-17. https://doi.org/10.5802/crgeos.146
- Gautier E, Dépret T, Cavero J, Costard F, Virmoux C, Fedorov A, Konstantinov P, Jammet M, Brunstein D. Fifty-year dynamics of the Lena River islands (Russia): Spatio-temporal pattern of large periglacial anabranching river and influence of climate change. *Sci Total Environ*. 2021 Aug 20;783:147020. https://doi.org/10.1016/j.scitotenv.2021.147020
- Bernus, A., Ottlé, C., 2022. Modeling subgrid lake energy balance in ORCHIDEE terrestrial scheme using the FLake lake model. *Geosci. Model Dev.* 15, 4275–4295. https://doi.org/10.5194/gmd-15-4275-2022
- Zhou, X., Polcher, J., Dumas, P., 2021. Representing Human Water Management in a Land Surface Model Using a Supply/Demand *Approach. Water Res* 57. https://doi.org/10.1029/2020WR028133
- Assessing the simulation of snowfall at Dumont d'Urville, Antarctica, during the YOPP-SH special observing campaign, Roussel M-L, Genthon C, Vignon E, Bazile E, Agosta C, Berne A, Durán-Alarcón C, Wiener, V, Dufresne J-L, Claud C, QJRMS, https://doi.org/10.1002/qj.4463

Land biogeochemistry, Ecosystems and Agriculture (BIOTECA)

Theme leaders
Nicolas Vuichard (LSCE-IPSL) · Frédéric Delarue (METIS-IPSL)

The theme in a nutshell

The theme "Biogeochemistry, terrestrial ecosystems and agriculture" (BIOTECA) aims to study the direct and indirect impact of anthropic activities on the biogeochemical cycles – mostly, carbon (C) and nitrogen (N) – in terrestrial ecosystems. BIOTECA therefore covers researches focusing on the C and N biogeochemical processes expressing at various spatial scales (molecular, watershed and global scales) and temporal scales (from the beginning of the industrial age until the next decades). BIOTECA promotes actions aiming to foster researches on this topic, as well as networking and collaborative actions on these topics within IPSL.

BIOTECA gathers the researches of ~40 scientists from five IPSL laboratories (LSCE, METIS, GEOPS, LOCEAN, ENS). METIS and LSCE are the two main laboratories involved in the actions of BIOTECA. As a consequence, the two co-leaders (Frédéric Delarue-METIS, and Nicolas Vuichard-LSCE) originate from these two laboratories.

Major tools. The diverse research activities developed within BIOTECA are studied with a wide panel of methodological approaches. The most used and developed in the theme consist in Gas chromatography / Mass spectrometry for analyzing Soil structure; gamma spectrometry for quantifying natural and artificial radioisotopes in sediments for instance; large-scale process-based model (ORCHIDEE model developed at ISPL) for studying the evolution of carbon and nitrogen cycles of terrestrial ecosystems.

Major projects. Among the structuring projects of the scientific communities involved in BIOTECA, one can cite the French Convergence Institute CLAND which fosters researches on land-management solutions for managing the ecological and energy transitions of the 21st century, and more important in terms of interactions within BIOETECA, the recent funding through the exploratory Priority Research Programs and Equipment "FairCarboN" (fourth program of investments for the future, national program). FairCarboN focuses on the carbon cycle in order to identify ecological, agronomic and socio-economic levers and trajectory scenarios for achieving carbon neutrality and restoring natural resources in continental ecosystems. FairCarbon is a federative program for the french "Carbon" community with a funding over the next 8 years for 40M€. It is co-led by Pierre Barré, researcher at ENS-Geo and Philippe Peylin (LSCE) is co-leader of one Targeted Project (Project Cible) on Observational databases and their use for modelling infrastructure. Both belong to IPSL and are part of the BIOTECA theme.

Opportunities and limitations. The numerous scientific communities represented with BIOTECA may offer potential opportunities for developing collaborative transthematic actions, but it remains highly challenging to identify scientific-bridging actions that might be of interest for the different communities. Another limitation we

experienced within BIOTECA is the low funding relatively to the size of the community. This makes impossible or very difficult to fund projects for which hiring manpower is the type of expanses needed.

Summary of activities in the last 5 years.
Main achievements of the BIOTECA theme over the first five years of the EUR consist in:

- The creation of a metadata catalog produced within the theme and aiming at (i) gathering information on data already produced by the BIOTECA research community and (ii) communicating about the development of this metadata catalog towards scientists from the theme. This action echoes demand from institutions, citizens for open publications, but also forpublic access to data. This metadata catalog benefits from the support of ESPRI-OBS. Here is an example of data in the catalog: https://doi.org/10.14768/6800b065-dcec-4006-ada5-b5f62a4bb832 (Belviso *et al.* 2020).
- An ambitious experiment unifying researches developed within BIOTECA, the "BIOTECA-Ecolab" experiment. It aimed to simulate the 2022 drought on plant-soil systems and to investigate their effects on soil C and N cycle- The development of user-friendly interface for the ORCHIDEE model. The model has a high potential for education application on ecosystem functioning and services but its command-line interface prevents its use by a large non-expert public. The development of the interface aims to fill this gap and to propose a set of educative material using ORCHIDEE. This action is planned for the second semester of 2023.
- The funding of "Master 2" internship bonuses for two to five internships per year.

Main orientations. For the next five years, and based on the difficulty of finding scientific projects gathering the different communities, BIOTECA will orientate its actions as an incubator of ideas favoring the emergence of new concepts and innovative approaches on two structuring axes:

1. From micro-to macroscale climatic conditions in land ecosystems and agriculture;
2. The Global Land Surface Model: ORCHIDEE. (ORganizing Carbon and Hydrology In Dynamic Ecosystems Environment).

Activities (2022-2023)

Bringing together geophysicists, biologists, geochemists and ecosystem modelers from ENS, LSCE and METIS laboratories, the "BIOTECA-Ecolab" experiment was conducted from February to April at the CNRS Ecotrons infrastructure (UMS 3194) managed by Samuel Abiven (ENS). More specifically, experiments will be performed in Ecolab systems allowing accurate real-time monitoring of environmental conditions (temperature, soil humidity and luminosity). Several BIOTECA meetings have been organised to design this experience, which took place in early 2023.In this experiment, the 2022 drought was simulated to assess:

- The effect of climate extreme on the physiology and photosynthetic properties of plant, especially poplar and hydrangea, a plant species highly sensitive to drought;
- The effect of climate extreme on the soil C and N cycle with a special emphasis on the role of root exudates, which will be tracked owing to ^{13}C labelling of climate chamber atmosphere;

- The role of biochar – by-product of plant pyrolysis presented as a possible tool to mitigate climate change in the last IPCC report – on plant health and on the soil C and N cycle;
- The effect of climate extreme on bacterial 3-hydroxy fatty acids in soils, which are used as an air temperature proxy in paleoenvironmental reconstruction.

The "BIOTECA-Ecolab" experiment is now over and sampling/analyses/data processing are in progress. This experiment will benefit from the metadata catalog initiative produced within the theme and will be a key component of communication activities.

In addition to "BIOTECA-Ecolab" experiment, the BIOTECA theme also encouraged an action dedicated to the study of the impact of land use on soil erosion (O. Evrard and A. Foucher; LSCE). As a consequence of land use change and intensification of farming practices, soil erosion has accelerated during the last several decades in many regions of the world. This led to an increased production of sediments implying disturbance of aquatic habitats and siltation of reservoirs with potentially contaminated sediment. In order to manage this excessive supply of sediment to the rivers, a preliminary requirement is to identify the sources providing this material, and to quantify their respective contribution to sediment. This is conducted through the investigation of the sediment fingerprinting (determination of multiple physico-chemical properties such as radionuclides, elemental and isotopic geochemistry, colour…) in the Salto Grande Dam river basin scale (Uruguay), which is subjected to an intense land use modification (towards agricultural pratices).

Highlight

Garnier *et al.*, Journal of Environmental Management, 2023: How much can change in the agro-food system reduce agricultural nitrogen losses to the environment? Example of a temperate-Mediterranean gradient?

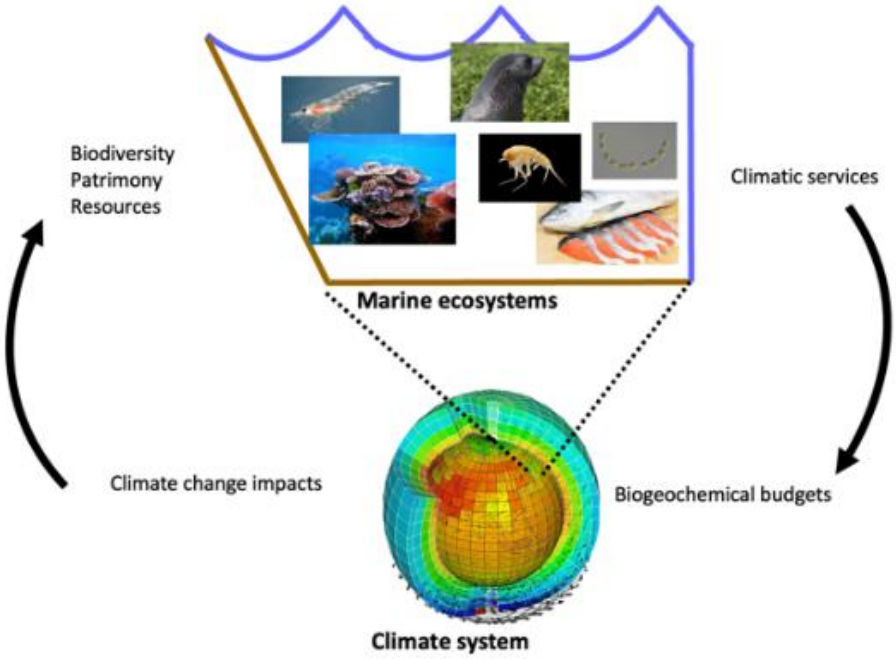
Ammonia volatilization, nitrous oxide emissions, and nitrate (leaching from agriculture cause severe environmental hazards. A at the regional scale, ammonia volatilization, nitrous oxide emissions, and nitrate leaching reflect the structure of the agro-food system. By analyzing N fluxes through the agro-food systems of a Temperate-Mediterranean gradient (France, Spain, and Portugal) experiencing contrasting climate and soil conditions, Garnier *et al.* (2023) assessed N fluxes from soils and livestock systems. They observed that N losses were closely related to the intensity of fertilization and the degree in agriculture system specialization. They also explored the impact of two future scenarios at the 2050 horizon: (1) a scenario based on the prescriptions of the EU-Farm-to-Fork strategy (F2F; 25% of organic farming, 10% of land set aside for biodiversity, 20% reduction in N fertilizers, and no diet change) and (2) an agro-ecological (AE) scenario with generalized organic farming, reconnection of crop and livestock farming, and a healthier human diet with an increase in the share of vegetal protein to 65% (i.e. the Mediterranean diet). Results showed that the AE scenario would reduce NH_3, N_2O, and NO_3 – emissions by up to 60-81%, while the F2F scenario would lead to a reduction in N losses by up to 24-35%.

Marine biogeochemistry, ecology, and resources

Theme leaders
Marion Gehlen (LSCE-IPSL) · Francesco d'Ovidio (LOCEAN-IPSL)

The theme in a nutshell

This theme explores the multiple interactions between marine biota and the climate system is developed along 4 main objectives: (1) the reduction of uncertainties of carbon export estimates to meso-pelagic and deep oceans, (2) the evaluation of the role of acclimatization/adaptation in the response of phytoplankton to climate change, (3) the quantification of fluxes at ocean boundaries and the contribution of ecosystems at the land-ocean transition to local and global C budgets, (4) the integration of tracer information into biogeochemical budgets and the (5) scientific support to conservation.



The theme involves about to 100 scientists in 4 labs (LSCE, LOCEAN, LMD, METIS).

Major tools. Models (including the climate model IPSL-CM6A-LR and specific biogeochemical and ecological models (e.g. PISCES and DARWIN)), implication in several international observing programs and campaigns (CMEMS, EURE4CA, THEMISTO, SO-CHIC), one national observing system (OISO). Internationally recognized expertise on ocean biophysical coupling processes, animal telemetry, carbon cycle, spatiotemporal scale interactions.

Major projects. The contribution of IPSL scientists to IPCC and the need to model the Earth system remains a strong structuring force for integrating together physics, biogeochemistry and biology of the ocean at multiple scales, and for studying feedbacks between the climate and marine ecosystems. The presence of the National Museum of Natural History (NMNH) within IPSL provides also a privileged channel for reaching policy makers and linking our research activity to conservation. A great

advantage for the IPSL community is the possibility of access to a large range of latitudes and environment gradients, thanks to the worldwide distribution of French EEZs, a strong network of international collaborations, and a good infrastructure for performing coastal and high sea experiments. IPSL also includes an active and internationally recognized group of scientists studying the marine carbon cycle from in situ observations to its representation in statistical and numerical models. They contribute to international efforts in carbon cycle monitoring through recurrent sampling programs and the release of products of surface ocean carbon system variables. Finally, a group of specialists in ocean tracer geochemistry equipped with cutting edge tools for sampling, analyzing and modeling of tracers, as well as paleo oceanographers using proxies developed based on the knowledge of ocean tracers.

Recent advances in the field from the IPSL community. The main contributions of our community are in terms of the Coupled Model Intercomparison Project (CMIP6) IPCC reports, and focus on models and process studies of climate-biogeochemistry feedbacks with special emphasis on the carbon cycle. Emerging actions point towards the exploration of marine biodiversity and its ecosystem services, by innovative approaches (including AI) that merge models, in situ observations (from marine telemetry to genomics) and ocean physics. Other recent actions have been in (1) conservation, with for instance a contribution to the scientific basis for the establishment of the Marine Protected Area of St Paul and Amsterdam, and in (2) the marine carbon cycle with the release of products of surface ocean carbon system variables through CMEMS.

Opportunities and limitations in the theme. The advantages of the Theme are its great diversity, solid structure, and great scientific productivity, highlighted by roles in ICPP activities. These advantages are also its limitation. We believe that the Theme has no vocation to alter the IPSL IPCC dynamics that is already very effective. Our work therefore aims at overcoming barriers between labs and disciplines in order to activate the multilab (i.e., IPSL) potential elsewhere.

Summary of the activities of the last 5 years.

Main achievements and product deliverables:

1. the **development of the IPSL models (LOCEAN, LSCE, LMD)**: two studies were supported, **(i)** one contributing to extending PISCES, the biogeochemical/ecological component of the IPSL Earth system model to the analysis of the mercury cycle and the bioaccumulation of mercury in the food chain and **(ii)** one adding a coral module to the model of intermediate complexty iLOVECLIM.
2. the **development of novel analytical techniques**: analysis of 227Ac in 10 l seawater samples by MC-ICPMS
    a. initiation of a **seminar series on inter-disciplinary topics** started in 2020; since 2023 integrated with IPSL-LMD(ENS) seminar series
    b. organization of thematic days and **workshops**: KERTREND, see 2022-23 highlight (LOCEAN, LMD)
    c. not funded through IPSL, but involving several researchers:
        i. contribution to IPCC WG1 and 2 (LOCEAN, LMD, LSCE)
        ii. contribution to carbon cycle research: yearly Global Carbon Budget, REgional Carbon Cycle Assessment and Processes (RECCAP2-ocean), (LOCEAN, LMD, LSCE).

Main orientations. Our decision to put the priority (and most of funding) on an emerging science topic at the frontiers of IPSL research activities ultimately sets a large part of our research orientation. The post-doctoral project was selected through an open and competitive call. It reinforces an emergent approach targeting the integration of omic and environmental data with the objective to better understand present-day organism-environment association and their evolution under climate change. Several researches pursued similar approaches, both at LOCEAN and IPSL, which we hope can be consolidated over the coming months. Our strategic is, however, not at the expense of the general science carried out in the different labs. The latter is still supported through funding for internship and experimental work, as well as IPSL marine science days (e.g. focus on biogeochemistry in fall 2023).

Activities (2022-2023)

Main achievements and product deliverables.

- Development with colleagues at Genoscope of a commentary paper on climate genomics methods and the collaborations needed to support and expand the field for submission to a high-impact journal.
- Development of whole-genome dataset for circumpolar Antarctic toothfish populations – currently developing different filter-based datasets for downstream population structure analyses and genotype environment association (GEA) analysis.
- Development of Aerobic Growth Index (AGI) for Antarctic toothfish with collaborators from the University of Boulder and Bern.
- Development of catch-per-unit-effort (CPUE)-based Species Distribution Model (SDM) of Antarctic toothfish in the Weddell Sea with collaborators from AWI.
- Completed Antarctic Weddell Sea toothfish population structure analysis based on 3RAD reduced-representation sequencing markers. 20 000 SNPs developed; no structure identified. Write-up to follow completion of circumpolar dataset.

Contribution to Research-Training links.

- Contribution to the IPSL climate change summer school in 2022 and 2023 (organizing committee).
- IPSL-theme post-doc was invited to present her work at the Polar Marine Science GRC in Ventura, CA, USA from March 5-10, 2022.
- IPSL-theme post-doc presented her work at the BES Climate Change Genomics online workshop (Sep. 14-15, 2022).

Contribution to Communication activities.

- IPSL-theme post-doc assisted in the execution of, and presented her work at, the LOCEAN-co-organized meeting KERTREND in Paris from March 30-31.
- IPSL-theme post-doc was invited to present at COP27 Nov. 10 in Sharm el Sheikh, Egypt, in a live-stream session on Southern Ocean mitigation strategies for ecosystems under climate change, which was posted as a news item on the IPSL website.
- IPSL-theme post-doc participated in CCAMLR meetings in Hobart, TAS, Australia, including WG-FSA (Oct. 10-20) and the SC-CCAMLR (Oct. 24-28).
- IPSL-theme post-doc participated in the CCAMLR workshop on phase 2 of the development of a Weddell Sea MPA in Oslo, Norway (Sep. 27-29).

Highlight

The **KERTREND meeting** took place from 30-31 March 2023, organized by researchers from IPSL-LOCEAN, the MNHN, and CEBC, and connected to the subject of the IPSL-theme postdoc. The meeting showcased the latest research on the Kerguelen plateau from the physical system to the ecology of top predators. The meeting took place in the auditorium of the Gallery of Evolution at MNHN, and was fully hybrid, with all presentations streamed online, as well as several online presenters. The Kerguelen plateau, a rich subantarctic habitat, has long been the focus of oceanographic and ecological monitoring work, given its critical importance for large birds and mammals, as well as its economic importance as a French EEZ, where there is an active fishery for Patagonian toothfish.

The IPSL-theme post-doc presented her work on Climate Genomics of Antarctic toothfish during the second session on tools for observations. The presentation was well-received, and stimulated discussions of potential applications of the approaches discussed (in particular genotype-environment association, GEA, analysis, and genetically-informed species distribution modelling, gSDM) to the closely related Patagonian toothfish. In addition to presenting her work, the IPSL-theme postdoc assisted in the meeting organization, chairing the fourth session on higher trophic-level communities. The four sessions were followed by a round table discussion, including the meeting conveners as well as the meeting attendees (~80 persons).

Main Publications (100% Open Access)

- Submission of paper on the development of 3RAD reduced-representation with colleagues at BeGenDiv to Molecular Ecology Resources (under review).
- Submission of working paper to upcoming CCAMLR Workshop on Age Determination (WS-ADM).

All publications referring to the theme are listed here:
https://www.ipsl.fr/recherche/les-thematiques-scientifiques/biogeochimie-marine-ecosystemes-et-ressources/les-publications/

Atmospheric composition and air quality (Composair)

Theme leaders
Juan Cuesta (LISA-IPSL) · Valérie Gros (LSCE-IPSL) · Karine Sartelet (CEREA-IPSL)

The theme in a nutshell

COMPOSAIR focuses on the formation and evolution of chemical compounds in the atmosphere from the boundary layer to the stratosphere. It focuses on the life cycle of atmospheric that impact health, ecosystems and the climate, such as ozone, aerosols, and their precursors such as nitrogen oxides or volatile organic compounds. This involves the research units: CEREA, LATMOS, LERMA, LISA, LMD, LSCE, METIS, representing about 140 researchers, engineers and technicians that are members of the theme.

Major tools. Measurement tools include instrumental sites (SIRTA, QUALAIR, LISA), a simulation chamber (CESAM) and a large spectrum of field deployable instruments and remote sensing probes. Modeling covers the global (LMDz), the regional (POLYPHEMUS, CHIMERE), the street (MUNICH) and ultra-local (Code_Saturne) scales, as well as explicit chemistry (Gecko-A), aerosol models (SSH-aerosol), and tools to represent multi-environment exposition (Explume) and emissions (Olympus, Orchidee). Satellite observations are also intensively used for characterizing the atmospheric composition (IASI, TROPOMI, GOME-2, etc.), derived both operationally by space agences and from research approaches developed by IPSL laboratories.

Major projects. A major momentum that has been structuring the community for the last couple of years is linked to 3 ANR projects (ACROSS, sTREEt, H2C), which led to international field campaigns in summer 2022 in Île-de-France focussed on mixings of urban pollutants and biogenic species. The measurements are used by modelers, such as in the European Greendeal project RI-URBANS.

Recent advances in the field from the IPSL community. The highlights presented at our annual general assembly are briefly presented here: (i) People exposure to outdoor pollution is strongly influenced by local effects, and also by micro-environments, as shown by experimental and modeling work. A new participatory science project has been initiated around sensors and an open-source platform. (ii) First modeling studies of oxidative potential, an important metrics for aerosol toxicity, have been performed. (iii) New premises for the SIRTA observatory with (among others) up and running IPSL IPRAL Lidar. (iv) Rivers of smoke over Southern Africa lead to large quantities of particles and gas transported to Indian Ocean with radiative impacts. Another study has shown that biomass particles absorbing properties evolve as they are transported. (v) Hunga Tonga major eruption plume was observed and characterized with IASI. (vi) The impact in atmospheric pollutants due to the lockdowns in Europe during COVID-19 pandemic.

Opportunities and limitations in the theme. Opportunities: many researchers are working together, and air-quality institutes such as Airparif are interested in our work with several joint projects that composair tries to federate. Limitations: little funding.

Summary of the activities of the last 5 years. Composair has initiated/funded research on (i) the impact of the COVID lockdown on air quality, (ii) improvements of the modeling of secondary organic aerosol formation, (iii) the synthesis of markers of sources and processes of formation of secondary organic aerosols, (iv) measurements of NH_3, (v) sources of volatile organic compounds in urban areas, (vi) the impact of 3D winds on surface VOC measurements and (v) the injection height of biomass burning aerosol plumes. Composair has funded 6 internships and 2 postdocs (2 months and 5 months). Composair has contributed to several articles and short videos published on the IPSL website and an international press conference to present the summer 2022 field campaign.

Main orientations. Three main orientations are foreseen for Composair. The first one concerns the understanding of pollutant emission, formation and impacts following the 2022 campaigns. The second one concerns fire emissions and impacts, with several research projects coordinated by COMPOSAIR participants that have started recently. Finally, a new structuring IPSL project is conducted by COMPOSAIR on people exposure, which will be better assessed by combining sensor measurements and modeling.

Activities (2022-2023)

Main achievements and product deliverables. After 2 years of intensive preparation, the field campaigns from the projects (Street, Across and H_2C) successfully took place in June-July 2022. They have involved several (>100) national and international scientists and several measurement sites in and around Paris (including airborne measurements for the Across campaign). A very exhaustive and unique dataset on gaseous and particulate pollutants has been obtained and will become available for the community. Outcomes of the campaigns include additional measurements (pesticides, secondary organic aerosol tracers…) which have been measured under the framework of Composair synergy initiatives.

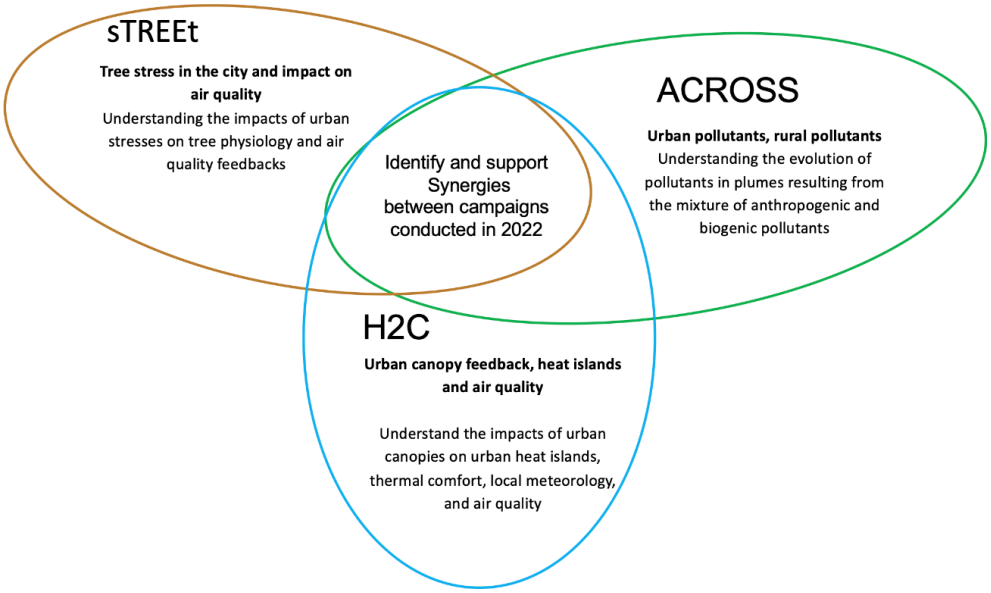
Contribution to Research-Training links. Composair has funded 3 internships and two postdocs (of 2 and 6 months).

Contribution to Communication activities. In the context of the launching of the international field campaign of summer 2022 in Paris, Composair has contributed to short presentation videos published on the IPSL website and to an international press conference that has led to several articles in the press.

Highlight

The intensive measurement campaigns in the summer of 2022 were marked by several events: heat waves and fire transport episodes. Numerous radiosondes of temperature, wind, turbulence, and aerosol profiles have been carried out, allowing a complete characterization of the dynamics and the identification of nocturnal jets leading to a weak temperature inversion and an early development of the boundary layer. Detailed measurements of particle composition showed high concentrations of organic compounds, notably during the heatwave at several sites in and around Paris. The origins of these particles are not yet well determined. They may have several origins. Some could come from emissions from fires that took place in Gironde and whose emissions were transported to the Paris region. Others could come from

gaseous volatile organic compounds that undergo physicochemical transformations in the atmosphere. These volatile organic compounds are partly emitted locally, by vegetation but also by asphalt. Recent studies have shown that biogenic emissions in urban areas such as Paris are not considered in the models, as well as those from asphalt, which could contribute to the formation of organic particles, particularly during heat waves. Preliminary results have been presented during 2 sessions at the European Geophysical Union Conference in April 2023 and will lead to many publications.



COMPOSAIR's support for the scientific synergy ACROSS-sTREEt-H2C.

Solar Systems

Theme leaders
Fabien Stalport (LISA-IPSL) · Emmanuel Marcq (LATMOS-IPSL)

The theme in a nutshell

The exploration of the Solar system and discovery of exoplanets now allow for comparative studies of Earth and its various extra-terrestrial analogues. IPSL is involved in these studies through its broad expertise, which incidentally allows for testing its Earth models in extreme conditions.

About 80 permanent staff (researchers, professors and engineers) and 80 non-permanent staff dispatched mainly among four IPSL laboratories (GEOPS, LATMOS, LISA, LMD). The theme is further subdivided into four coupled sub-themes: **Extraterrestrial climate models** (Mars, Venus, Titan, Pluto, giant planets, exoplanets); **Sun-planets relations** (study of interactions between the interplanetary medium and the upper layers of atmospheres); **Astrobiology** (study of extraterrestrial organic matter); **Interiors-atmospheres coupling** (study of surfaces and subsurfaces).

Major tools. Various modeling tools are used to interpret the observational data gathered in the solar system (see below), complemented by astronomical observations. These models include climate models, closely related to the IPSL Earth Planetary Climate Model, as well as laboratory simulations aimed at reproducing the exotic conditions found in the solar system and in exoplanets.

Major projects. We are involved in the scientific team on some past and present space missions (Rosetta, Venus Express, Mars Express, TGO…) to interpret their observations. We are also involved in the development of numerous instruments and space missions which will be launched in the next decade: **WISDOMOON** that will analyze the subsurface of the Moon, **WISDOM** and **MOMA** part of the ExoMars 2020 rover that will analyze the subsurface of Mars; **MIRS** onboard MMX that will explore the Martian system; **DRAMS** on board Dragonfly which will characterize the Titan's surface; **ARIEL** which will characterize the atmospheres of exoplanets; **EnVision** and **DaVinci** which will characterize the surface and atmosphere of Venus; **JUICE** which will study the icy moons of Jupiter.

Recent advances in the field from the IPSL community.

- Venus Climate Database updated v2.2: http://www-venus.lmd.jussieu.fr/vcd_python/
- JUICE mission successfully launched from ESA spaceport in Kourou.
- FRIPON project: recovery of a large number of meteorites in Normandy: https://www.vigie-ciel.org/2023/02/22/meteorites-normandes-bilan-dune-folle-semaine/

Opportunities and limitations. IPSL does not encompass all laboratories in Paris region involved in the theme, so that regional framework and most collaborations are external to IPSL. On the other hand, space missions imply large international collaborations, which is both a strength (more ambitious scientific objectives) and a risk (subject to political, economic and diplomatic context).

Summary of the activities of the last 5 years. While data sets from older missions were still being processed (e.g. Venus Express 2006-2014, Rosetta 2014-2016), several new explorations in which IPSL theme members are involved were successfully launched: Bepi-Colombo in 2018, towards Mercury; Insight, first seismometer to Mars in 2019; Mars 2020 rover in 2021; JUICE in 2023, towards the Jovian system. Some team members are also working on modeling exoplanetary observations (atmospheric dynamics, composition) acquired by the JWST launched in 2021. Instrumental conception and preparation of observation processing has also begun on recently selected missions such as Dragonfly (towards Titan, to be launched in 2027) and EnVision (towards Venus, to be launched in 2031).

Main orientations. Orientations are mainly dictated by the future agenda of space exploration missions, and many members of the theme are involved in the development of these future missions. A growing interest and investment in exoplanetary studies has also been noticeable for about a decade.

Activities (2022-2023)

Main achievements and product deliverables.

- Evidence for SO_2 photochemical production in the atmosphere of the giant exoplanet WASP-39b (Tsai et al., accepted in Nature, 2023).
- BepiColombo mission confirms stagnation region of Venus magnetosheath and reveals its large extent (Persson *et al.*, *Nature Communications* 2022).
- Detection of recent meteoroid impacts on Mars using both seismic and acoustic waves using InSight seismometer (Garcia *et al.*, Nature Geoscience, 2022).
- Discovery of a shear zone in Valles Marineris, possibly associated with the large impact which created the North-South dichotomy of Martian surface. (Gurgurewicz *et al.*, *Nature Communications Earth & Environment*, 2022).

Contribution to Research-Training links. Steady flux of graduate students (~5/year) and interns at graduate and undergraduate level (~20/year) working under the supervision of the theme members. About 1/3rd of the staff teaches (~0.5 FTE/person) in various universities in or near Paris in physics/chemistry, atmospheric science, geology, astronomy and planetary science at undergraduate and graduate levels. The specific IPSL contribution deals with specific financial support to students and early career scientists in national and international events (Rencontres Exobiologiques pour Doctorants, Mars Workshop, Exobiologie Jeunes Chercheurs…)

Contribution to Communication activities. Space-related science is very popular among the general public, which reflects in the broad involvement of many team members in outreach through various media (radio, TV, print media) depending on the actuality of space and planetary exploration. At an internal IPSL level, theme members collaborate with IPSL during major events like “Fête de la Science”.

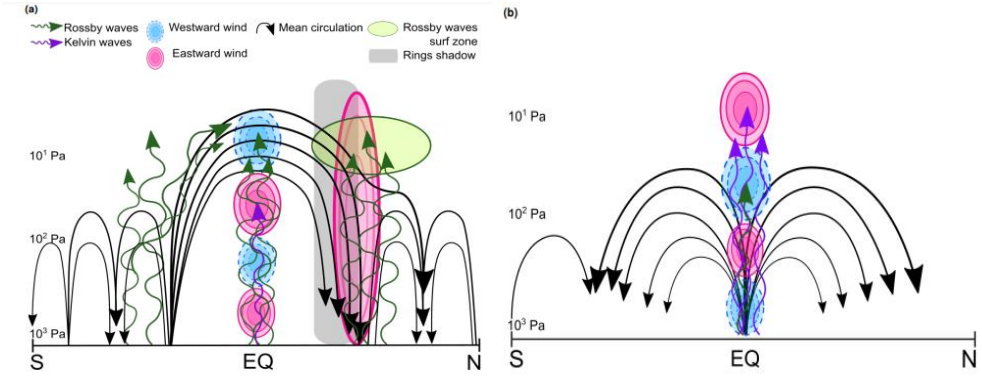
Highlight

Joint evolution of equatorial oscillation and interhemispheric circulation in Saturn’s atmosphere.

Planetary stratospheres are characterized by a subtle interplay between dynamics, radiation and chemistry. Observations of Saturn’s stratosphere have revealed a semi-annual equatorial oscillation of temperature and hinted at an interhemispheric circulation of hydrocarbon species. Both the forcing mechanisms of the former and

the existence of the latter have remained debated. Here we use a new troposphere-to-stratosphere Saturn global climate model to argue that those two open questions are intimately connected. Our Saturn climate model reproduces a stratospheric oscillation exhibiting the observed semi-annual period, amplitude and downward propagation. In the same Saturn simulation, a prominent stratospheric summer-to-winter hemispheric circulation develops at the solstices, controlled by both the seasonal radiative gradients and Rossby-wave pumping in the winter-subsiding branch, analogous to Earth's Brewer-Dobson circulation. Furthermore, we show that Saturn's equatorial oscillation is driven by the seasonal variability of both the resolved planetary-scale wave activity and the interhemispheric circulation, akin to Earth's Semi-Annual oscillation.

Deborah Bardet, Aymeric Spiga & Sandrine Guerlet (LMD), published in *Nature Astronomy* (2022).



Saturn's stratospheric dynamics during northen winter (a) and equinoxes (b).

Statistics for Analysis, Modeling and Assimilation (SAMA)

Theme leaders
Adriana Coman (LISA-IPSL) · Cécile Mallet (LATMOS-IPSL) · Soulivanh Thao (LSCE-IPSL)

The theme in a nutshell

The SAMA theme at IPSL aims at improving the data analysis of observations, numerical outputs and their coupling. The final goal is to better represent the climate, geophysical fluids, their constituents and improve their forecast. These objectives can be achieved by leveraging recent mathematical and methodological developments. In the IPSL community, the development of observation and modeling tools has been dazzling, generating considerable amounts of data. This explosion of data offers researchers a wealth of information. At the same time, machine learning applications carried by the computer vision community have entered an era where tasks unimaginable a few years ago are now possible. The challenge is to create a new vision of data analysis in synergy with existing models and notably with the help of machine learning.

SAMA has historically been grouped around 3 sub-themes: data assimilation, statistics, neural network. Because of the transdisciplinary nature of the theme, the number of researchers concerned cannot be precisely assessed. The team is made up of all IPSL researchers who wish to carry out actions in order to achieve the objectives mentioned in the introduction. Based on recent events organized by SAMA, we can however say that there are at least 50 (permanent and non-permanent) researchers, spread over IPSL laboratories, that are working on topics covered by SAMA.

Major tools and projects. The SAMA group has not specific major projects at IPSL level during the last period but rather it is attached to developing transversal approaches in data science, to promote the emergence of methodological developments in several teams of the IPSL. Through numerous internships, workshops, seminars, the objective is that IPSL actively participates in the construction of a lasting synergy between two major current scientific paradigms: the paradigm of numerical modeling of climate and the more recent paradigm of data sciences. As an example, we give here two ongoing projects.

XAIDA – eXtreme events: Artificial Intelligence for Detection and Attribution (H2020 Grant No 101003469). This project is led by CNRS-IPSL and VU Amsterdam and consists of a consortium of sixteen European research institutes who are joining forces with climate risk practitioners to better assess and predict the influence of climate change on extreme weather using novel artificial intelligence methods.

ARGONAUT – PollutAnts and Greenhouse Gases EmissiOns MoNitoring from SpAce at high ResolUTion (ANR-19-CE01-0007). The main objective is to apply atmospheric inversion using the Community Inversion Framework (CIF), a state-of-the-art variational assimilation system developed at **IPSL** to determine pollutants and CO_2 emissions at politically relevant scales in France, based on the last generation of satellite imaging (NO_2, CO and HCHO from **TROPOMI**, and in the future of CO_2

and NO_2 from **CO2M**). Combined with the high-resolution imaging of these instruments, these multiple species observations will allow one to evaluate the correlation between the co-emitted species for a given source and to better separate sources from the national to the local scales in using variational assimilation methods.

Recent advances in the field from the IPSL community. Machine learning for subgrid parametrisation and model tuning: MOGPA Project Hermès (HRMES: High-Resolution Modeling of the Earth System), Hourdin *et al.* (2021), Process-Based Climate Model Development Harnessing Machine Learning: II. Model Calibration From Single Column to Global. A new deep learning approach to retrieve geophysical products (rainfall fields) from satellite remote sensing observations (Viltard 2023).

Summary of the activities of the last 5 years. One of the main objective of SAMA is to reinforce the links between IPSL and/or external actors in order to provide new innovatives tools that are relevant for the other IPSL research themes. To do so, SAMA rely on several action renewed every year:

- **IA for Climate multidisciplinary research Master internships** (Sylvie Thiria and Cécile Mallet), more than 40 internships since 2018.
- **Journal club on Machine Learning for Earth System Modeling** (Redouane Lguensat): https://ai4climate.lip6.fr/category/journal-club
- Organization of **seminars AI4Climate** list of seminars: https://ai4climate.lip6.fr/list-of-the-seminars/
- **One-day SAMA workshop (2018, 2022, 2023):** Overview of SAMA activities within IPSL and to reinforce bonds between the IPSL and/or external actors.
- Financial participation to workshops and summer schools: e.g VALPRED.

With the newly created ESPRI-IA within IPSL we have started to work to strengthen the links with other themes that use SAMA tools/concepts and to work in synergy to advise in the fields of software engineering and data processing, especially in Machine Learning and Deep Learning methodology. There is thus interaction and complementarity with ESPRI-IA, the aim being to keep a link between the research activities and the technical and engineering part. Always in a spirit of collaboration with the Observation Pole of the ESPRI team, we participate in actions whose main objective is to create a catalogue of existing data in all the IPSL labs and thus constitute a data set on which we can train ourselves to apply AI methods.

Contribution to Research-Training links. A first session of a **free training course for deep learning** applied to climate observation was organized in November 2021 in collaboration with SCAI (13 participants). A second session will be organized current 2023.

We also note the participation of SAMA members in the **MPT, SGE, WAPE, MOCIS & ECLAT masters**, responsibility for a Master in AI (TRIED) as well as doctoral school courses for PhD students (statistics, e-learning platforms, data assimilation).

Contribution to Communication activities. Annual poster session organized with the Sorbonne Center for Artificial Intelligence (SCAI) from the studies carried out during IA for Climate multidisciplinary research Master internships.

Création du GDR "Défis théoriques pour les sciences du climat": https://defi-theo-climat.ipsl.fr

ClimarisQ, a serious game based on IPSL work on detection and attribution: https://climarisq.ipsl.fr

Participations au Workshop "Data science and modeling for the environment" organisé par SCAI.

Main orientations. The SAMA theme is now well structured internally and is now focusing on developing collaborations with the SU (SCAI) and Paris-Saclay (DataIA) AI institutes. In the coming years, the aim will be to concretise these collaborations through concrete projects in climate science related to the key issues of statistical learning.

Activities (2022-2023)

Main achievements and product deliverables.

- **IA for Climate multidisciplinary research Master internships** (ongoing 7 (EUR)+3 (SCAI)/ Sylvie Thiria and Cécile Mallet).
- **Journal club on Machine Learning for Earth System Modeling** (Redouane Lguensat): https://ai4climate.lip6.fr/category/journal-club/ttps://ai4climate.lip6.fr/category/journal-club/
- Organization of **seminars AI4Climate** list of seminars: https://ai4climate.lip6.fr/list-of-the-seminars/
- **Workshop SAMA 11 April 2022**: Overview of SAMA activities within IPSL and to reinforce bonds between the IPSL and/or external actors:
- program https://www.ipsl.fr/agenda/archives-evenements/journee-sama/
- Financial participation to VALPRED summer school 2023: https://wintenberger.fr/VALPRED.html

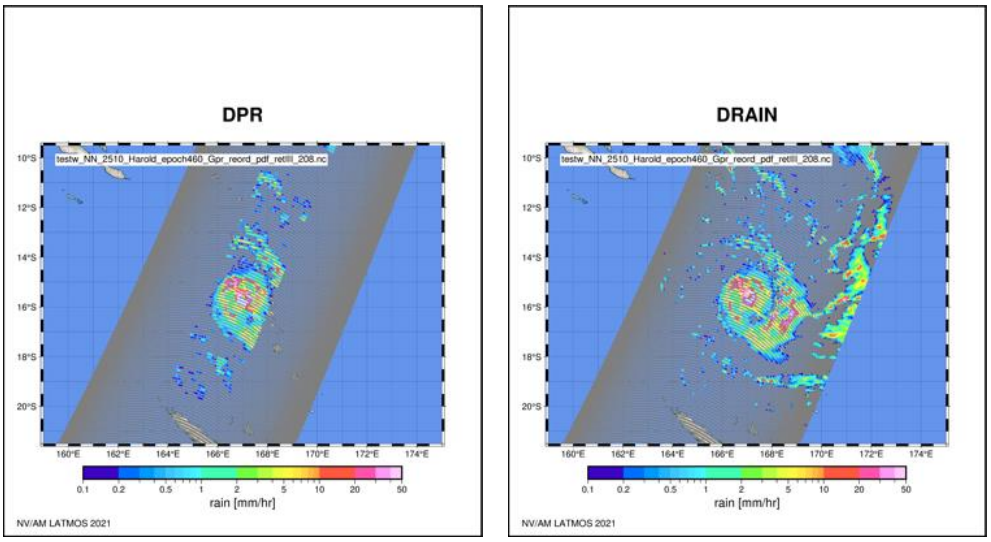
Contribution to Research-Training links. Participation of SAMA members in the **MPT**, **WAPE**, **SGE**, **MOCIS** & **ECLAT masters**, responsibility for a Master in AI (TRIED) as well as doctoral school courses for PhD students (statistics, e-learning platforms, data assimilation).

Highlight

Retrieval of rain from Passive Microwave radiometers data has been a challenge ever since the launch of the first Defense Meteorological Satellite Program in the late 70s. Enormous progress has been made since the launch of the Tropical Rainfall Measuring Mission (TRMM) in 1997 but until recently the data were mostly processed on a pixel-by-pixel basis.

Advances in Deep-Learning algorithm applied to computer vision offers a whole new way to tackle the rain retrieval problem. The Global Precipitation Measurement (GPM) Core satellite carries a passive microwave radiometer (GPM Microwave Imager, GMI) and a radar (Dual-frequency Precipitation Radar, DPR) that share part of their swath. The brightness temperatures measured in the 37 and 89 GHz channels are used like the RGB components of a regular image while rain rate from Dual Fre-

quency radar provides the surface rain. A U-net is then trained on these data to develop a retrieval algorithm: Deep-learning RAIN (DRAIN). With only four brightness temperatures as an input and no other a priori information, DRAIN is offering similar or slightly better performances than GPROF, the GPM official algorithm, in most situations. These performances are assumed to be due to the fact that DRAIN works on an image basis instead of the classical pixel-by-pixel basis.



Left, the rain rate estimated from the DPR on the GPM-Core satellite which is used to supervise the training of DRAIN. Note the difference in swath: DPR measures rain in a 245 km-swath while GMI offers a 904 km-swath. Right, the rain retrieved using DRAIN. Typhoon Harold, observed on April 6th, 2020 in the Pacific Ocean.

Estimating rain at a global scale requires however not just a single satellite but a constellation of satellites providing a high temporal and spatial sampling to overcome the very intermittent nature of rain both spatially and temporally. After addressing the rain retrieval from supervised approaches made possible with the combination of GMI and DPR data, the next challenge is to be able to develop a retrieval algorithm for all the satellites of the constellation which only offer brightness temperature measurements. Each of these satellites has a microwave radiometer which offers slightly different characteristics such that direct use of DRAIN is impossible. The next challenge is thus to set up some domain adaptation techniques in order to be able to use DRAIN for all the instruments. Preliminary tests have been made using Cycle-GAN approaches that appear promising but will require to be consolidated.

Urban Environment – Cross-cutting theme

Theme leaders
Simone Kotthaus (-IPSL) · Valérie Gros (-IPSL) · Gilles Foret (-IPSL)

The theme in a nutshell

The significant societal and environmental transitions expected for the upcoming decades are particularly critical in urban environments. Here, applied, inter-disciplinary research is urgently needed to inform political decision making and sustainable planning strategies.

The three overarching objectives of the new **IPSL Theme transverse "Environnements urbains"** are to:

1. increase the urban-related research activities at IPSL;
2. coordinate research activities within IPSL and also with external partners to enhance multi-disciplinary approaches;
3. strengthen and improve the interaction of IPSL research with urban stakeholders to increase societal impact.

IPSL aims to improve climate change projections and the assessment of potential impacts by developing climate services that benefit society. In the long-term, the theme aims to support the development of integrated urban services (IUS), that target challenges from multiple perspectives (incl. e.g. weather, climate, air quality, water, biodiversity, health, or energy).

The transverse theme is connecting urban-related research activities from three IPSL scientific themes, namely:

- Atmospheric composition and air quality (Composair);
- Land biogeochemistry, Ecosystems and Agriculture (BIOTECA);
- Water Cycle.

The theme is promoting research collaborations in the fields of *Météo et Climat Urbain* (e.g. at IPSL, LATMOS, LSCE, LMD, METIS), which is currently not structured in an existing IPSL scientific theme. The aim is to enhance knowledge exchange and collaborations between these three topics, and to create synergies with societal impact. It is also essential for the IPSL transverse theme on urban environments to strengthen the links to the local municipalities, namely the Ville de Paris and Region IdF. This is to be achieved by an increased engagement with several interdisciplinary initiatives and external partners that are promoting networking and coordination in the Paris region or globally.

Major tools. The IPSL urban theme has taken a leading role in the coordination of the multi-project initiative PANAME that motivates the pooling of resources, enables the efficient coordination of network observations and modelling studies, but also consolidates outreach and communication efforts. Implemented at the AERIS-ESPRI data centre, a dedicated web portal provides a valuable infrastructure for data collection, data base management, and appealing quick-looks.

Major projects. IPSL is involved in or collaborating with a large number of national and international projects that have selected the Paris region as their case study area with a strong component on atmospheric processes related to:

- air quality: ACTRIS H2020 RI-URBANS, ANR sTREEt, ANR ACROSS, ANR H2C, ARGONAUT;
- climate: ICOS-Cities H2020 PAUL, ERC URBISPHERE, ANR ARGONAUT, Copernicus $CoCO_2$, CORDEX flagship URB-RCC, PhD project RegIPSL development;
- meteorology/hydrology: WMO RDP Paris 2024 Olympics, ANR MOSAI, ANR H2C, Paris Region-funded PhD project DYNAMICS, LEFE INTERVILLE-CLIM, ORCHIDEE development;
- impact on human health and activities: ANR H2C, POLLUSPORT.

Summary of activities in the past 5 years. The theme is just starting in 2023, and relies on the momentum created by the coordination of the PANAME initiative, which is giving enhanced visibility to the Paris region atmospheric research. First results from the dedicated PANAME'22 measurement campaign are expected to result in a large number of high-impact publications.

Main orientations. While collaborations within IPSL and also external partners often connect the topics of COMPOS'air and Météo et Climat Urbain, it is the specific aim of the theme to further enhance interactions with Biotéca and Cycle de l'eau.

Activities (2022-2023)

Main achievements.

- PANAME 2022 field campaign;
- PANAME measurement network design and novel data products;
- To enhance the collaboration between Cycle de l'eau and the transverse urban theme, the topic of urban hydrology was selected as a focus subject. A PhD has just been funded by IPSL to conduct a comprehensive analysis on urban hydrology based on an integrated approach. The PhD aims at quantifying the impact of urbanization and soil sealing on precipitation and floods. This thesis is supervised through an inter-labo collaborations between LATMOS and METIS that was enable first by the water cycle theme through the support of an internship. Strong contribution on urban hydrology theme is expected from this water cycle related PhD.

Contribution to research and training.

- Lecture (Introduction to ground-based remote sensing) at the Bochum Urban Climate Summer School, 26-29 Sept 2022, Bochum, Germany.

Communication activities.

- CNRS press release PANAME, 10 June 2022:
- https://www.cnrs.fr/fr/paname-2022-des-campagnes-pour-etudier-la-qualite-de-lair-et-le-climat-urbain
- PROBE Stakeholder engagement workshop, Evora, Portugal, 06/10/2022;
- EGU2023 sessions organized in framework of PANAME projects: AS5.2: *Urban to rural atmospheric observations and models for multidisciplinary research* (ANR ACROSS) and AS 5.17: Research Infrastructures Services Reinforcing Air Quality Monitoring Capacities in European Urban & Industrial AreaS (RI-URBANS).

Highlight

The IPSL urban theme is taking a leading role in organizing the national workshop “Atmosphère, Climat et environnements urbains”at Sorbonne University 8-9 June 2023.

The objective of this workshop is to take stock of the scientific work carried out by the ocean-atmosphere national community on urban environments and their evolution. We also want to strengthen links with other scientific communities that are at the heart of urban issues (hydrology, water quality, vegetation, etc.) and reflect on multidisciplinary and multisectoral structures (links with operational, territorial actors, etc.) in which these works are taking place. This concerns cities in their great diversity, megalopolises, coastal cities, cities in the south, mountain cities.

This workshop must participate in the implementation of the INSU urban project to support the research actions of our community and respond to the important societal questions that arise in these environments.

The program will be as follows and will include contributions from the community:
Session 1. Scientific questions and obstacles in urban environments: points of view from the Ocean-Atmosphere field
Session 2. New tools for the study and monitoring of urban environments
Session 3. What future scenarios for urban environments?
Session 4. Round table: Research-society links for the city in the Ocean Atmosphere field
Session 5. Urban projects: what objectives and what structure?

Main Publications (100% Open Access)

- Atmospheric observations:
  - https://doi.org/10.5194/amt-16-433-2023
  - https://doi.org/10.5194/ESSD-14-5157-2022
- Air quality:
  - https://doi.org/10.5194/acp-2022-800
  - https://doi.org/10.1016/J.ATMOSENV.2022.119386

IPSL Climate services

Lead Robert Vautard (IPSL)

The IPSL Climate services activity, often called “IPSL Climate Services and Expertise”, has a major objective to provide tools, data and synthesize climate information for a successful transfer to decision makers, engineers, local and regional authorities, in view of climate change adaptation and mitigation. This activity aims to be at the same time deeply rooted in climate science and in co-construction with partners willing to use the information, benefitting from the experience of IPSL teams and data (ESPRI). There are different types of use of such information, depending on partners/stakeholders: quality-controlled data from climate model simulations (climate projections) used in prospective scenario modeling, risk analysis, syntheses of climate change information used in regional or local authorities plans, statistical methods for processing climate data… This activity, despite operational aspects, is an innovation activity. Our policy therefore implies that our projects must include a research component to a certain degree. Our strategic priority targets are to support production of knowledge for regional stakeholders and international (Europe and developing countries) through lead in several projects, national activities being mostly led by Météo-France.

The activity is currently concerning several IPSL laboratories (LSCE, LMD, LOCEAN, IPSL FR itself). In particular, the new “GREC francilien” activities (science-society exchange platform with regional authorities) has built upon the expertise of several IPSL labs, but also benefits from the partnership with the “Institut de la Transition Environnementale” of Sorbonne Université. Currently the activity involves about 20 scientists (engineers and researchers) within IPSL. The activity is mostly self-funded.

Major projects. IPSL is a contractor of the C3S for the provision of climate projections. IPSL co-leads with the Institut de la Transition Environnementale (ITE) the GREC francilien project. For near real time extreme event attribution, IPSL is a partner of the World Weather Attribution (WWA) network, which provides frequent syntheses of the relation between extreme events and climate change in particular in the Global South. The national EXPLORE2 project is designed to provide scenarios for river discharge and IPSL has a significant participation in the development of statistical methods for data processing.

Recent advances. The field of climate services has grown over the past few years. Scientifically speaking, statistical methods have considerably developed in several areas: processing and modeling of extremes, with probabilistic attribution and storylines, and real time applications. Bias correction (CDFt) and the multiple variants with intervariable correlation conservation, model selection methods, model processing to fit users’ requirements on time and space resolution. Many methods now become operational. The developments are important in particular for the energy sector. On the science-policy platform (GREC francilien), engagement of the City of Paris has grown, in several directions.

Opportunities and limitations. There are many opportunities for these activities, with a growing demand for climate information at all society levels. However the activity is facing several challenges: funding, while existent, remains limited given

the ambitions, projects with partners provide fragmented funding; the activity is yet considered as a peripheral activity and engineers and researchers are not well recognized for this time-taking and useful sciencesociety activity; the activity lacks mid-career managers, and often relies on senior scientists leading the activity as a side activity, and developments are made by young, fix-term contracts. The situation has however improved, and several new attractive activities raise growing interest (energy mixes, extremes, regional stakeholder discussion).

Activities over the past 5 years. The developments over the past five years have focused on (i) climate projection distribution service within the C3S programme, (ii) developing statistical methods for adapting projection data to stakeholder use, such as bias correction, model selection, extreme events modeling and attribution, in particular for developing countries (iii) applications for energy (RTE partnership, C3S Energy) and water management (project EXPLORE2), (iv) expertise to industry in the water and energy sector, and to regional stakeholders (interactions with the Ile-de-France region and Paris City).

Main orientations. The GREC francilien will remain a major activity, together with a long-term partnership with the RTE-France electricity transmission operator, for the development of energy mix scenarios, and with C3S for the energy sector. Thanks to the recruitment of a permanent engineer for developing data and methods for developing countries, this activity is currently being developed together with IRD scientists. High-level decision makers training is an emerging activity, through participation of IPSL to the government program of civil servant training (two successful sessions so far with government agencies leaders and administration heads), and participation to the organization of the 25000 state managers. IPSL is also currently developing training on climate change for decision makers in the finance sector.

Activities (2022-2023)

Main achievements.

- Start in 2022 of a new 5-year partnership with the RTE electricity transmission network in order to develop (i) statistical method to prepare projections data and climate indices for use to develop energy mix scenarios assessment for the government and the resilience of the network, (ii) development of methods to process extremes and project worst-case scenarios, (iii) investigate interactions between land use/management by the energy sector and the regional climate; The first achievement has been a method for model selection and the production of a hourly projection data set for European energy stakeholders;
- Start in 2022 of the contribution, as advisor and methodological development for the C3S-Energy service at global scale (no result yet, but methods discussed for implementation in the service);
- Development of a bias-corrected climate dataset for the water management at national scale (EXPLORE2 project);
- Development of a “bias correction service”, in order to respond to the many requests from various sectors;

- Production of several thematic booklets for the Île-de-France Region through the GREC Île-de-France (https://grec-idf.eu), and advices on major plans (adaptation, land use plan, for the Region and the Paris City); several more thematic booklets are underway;
- Development of a climate storyline of for extreme heat of 50°C in Paris (as part of a large-scale crisis exercise led by the City of Paris that will take place after the summer of 2023);
- Contribution to operational attribution in the WWA network: https://www.worldweatherattribution.org and to the national high council for climate reports. Training activities on ecological transition for (i) national administration managers and agency operational directors (2 sessions with ~20 participants each), (ii) contribution to the definition of the national programme for the training of 25000 manager civil servants and (iii) finance managers.

4

Training and education program

Leaders
Hervé Le Treut · Solène Turquety

Training and education activities. main goals

The very rapid evolution of climate and environmental transitions gives a rapidly growing importance to the different aspects of training, both higher education and professional training. In this context, the EUR "IPSL Climate Graduate School" (IPSL-CGS) is a strongly structuring project, which aims to provide an education through research that is recognized and attractive at national and international levels on issues related to the climate system, climate change and their impacts.

Many programs are proposed in Île-de-France on these topics in different universities and "grandes écoles", as introduced on the IPSL training web page (https://www.ipsl.fr/en/education/environment-and-climate-sciences/) and orientation tool (https://www.ipsl.fr/formation/orientation/). Doctoral studies in IPSL laboratories are mainly conducted within the doctoral school "Sciences de l'environnement d'Île-de-France" (SEIF, ED129). They are supplemented by contributions from three other doctoral schools: "École Doctorale Sciences Mécaniques et Énergétiques, Matériaux et Géosciences" (SMEMAG, UPSaclay), "École Doctorale Géosciences, Ressources Naturelles et Environnement" (GRNE at Sorbonne Université) and "École Sciences, Ingénierie, Environnement" (SIE, UPEC).

The activities are structured around 6 main objectives (Actions described briefly below) aiming at strengthening the training offered at Master and PhD level, fostering collaborations and promoting research opportunities at IPSL to international young scientists. They also allow a coordination of the different programs offered in Ile de France in the perimeter of the IPSL-CGS scientific themes.

Since 2019, the work undertaken on these actions has allowed to:

- Foster collaborations at IPSL level around teaching projects, the sharing of courses and field trips, the first steps of the development of e-learning courses providing a solid foundation in the key themes of IPSL;
- Support the emergence of a new master programs to address climate challenges;
- Develop new common teaching resources (books, e-learning material);
- Maintain and reinforce the offer for field training, site visits, and summer schools, some also allowing an international opening for master and doctoral students;
- Provide support for pedagogical innovation, through a call for proposal but also through the development of tools and services at IPSL: centralized numerical services and learning management system (LMS) in collaboration with the ESPRI team, JupyterLab environment to facilitate the creation of numerical teaching experiments (including the use of climate and air quality models developed at IPSL);
- Strengthen research training through support for doctoral schools;
- Promote training and teaching activities at IPSL level and beyond and organize networking events and opportunities.

Some activities are recurrent (summer schools, field trips) or long-term projects (writing a book, developing e-learning courses) involving teams of "enseignants-

chercheurs" from different institutions, involved in different courses. In addition to the achieved training or material, these projects are valuable in creating a close-knit community and facilitating collaboration and the sharing of activities and courses. The training courses organized for the contributors (e-learning for example) also encourage exchanges in addition to promoting pedagogical innovation.

Activities

Coordination.

The organization of the activities is supported by a committee composed of 20 lecturer-researchers ("enseignant-chercheurs") representing the various institutions and programs, with the project management and coordination team. The 6 actions defined at the beginning of the project have all been continued and have all been the subject of targeted meetings throughout the year.

The training opportunities are regularly communicated to the IPSL community, more specifically the open call for training projects, the proposed events and trainings, and the main achievements. The committee evaluates requests "as they come in" (more than 17 projects in the framework of its 2022-2023 call for proposals), with at least 4 committee meetings a year. It also develops more permanent actions (recurrent or longer-term). Key activities for each action developed in the past year are detailed below.

Action 1. Coordination / Federation of Master programs

This action aims at strengthening cooperation between the master programs related to climate in Ile de France Region through the sharing of courses; ensuring that each master student has the opportunity to go on a field trip and to have a practical introduction to numerical modeling; the development of summer schools; increasing visibility of complementary training opportunities at IPSL.

Activities in 2022-2023.

- The project of "e-courses for masters", dedicated to the development of common courses on climate-related science, is ongoing and making progress (see Action 5). It is developed as an online training (e-learning) aiming more particularly at master 1 level (e.g., to provide a knowledge base before starting a specialized M2), but some courses are also well suited for M2 or doctoral students as complementary training.
- The support to the development of educational resources and books introducing the fundamentals on key scientific topics for IPSL (as detailed in Action 5 and highlight for example) is important to foster collaborations between lecturers/researchers from different universities with complementary expertise and points of view.
- IPSL-CGS also allowed the organization of field trips (ateliers CLE, field work at OHP and OMP observatories, ship-based schools, site visits…) and summer schools (see Action 2).
- The role of IPSL at M2 level has been important to launch or renew Master programs, in particular transdisciplinary programs (Climat & Média, NewSpace…).

Action 2. International

The objective of this action is to strengthen the international attractiveness of IPSL's graduate programs; provide adapted information to international students; propose an international opening to graduate students in the IPSL programs.

Activities in 2022-2023.

The 4th edition of the IPSL "Virtual school" for international students is conducted in June 2023 and is dedicated to the water cycle. Support has also been provided for the organization of summer schools and international trainings (e.g., EIT Climate KIC program "Climate Leadership Journey", TRACING training), and of international field trips and measurements (e.g., student participation in an international campaign at sea).

Action 3. Pre-doctoral graduate program

IPSL-CGS introduced a pre-doctoral program for students graduating from M2 who were awarded a PhD grant. It consists in a preparatory period of 3 months (between October and December) before the start of the PhD.

Activities in 2022-2023.

3 students benefited from a 3 months part time contract to allow for initial training on their PhD subject and finalize a publication on their Master thesis.

Action 4. Support to doctoral schools

Activities in 2022-2023.

5 new doctoral students have been funded or co-funded (2 arriving with a foreign degree). The support to the doctoral school SEIF has also allowed to organize a 3-day workshop ("Journées des doctorants" (JDD)) in Dourdan, which was a big success with more than 110 participants. The program included a presentation of the doctoral school (for 1st year students), poster sessions to foster interactions on the large variety of research topics related to climate science, and allow the students to build their network. Several courses that must be validated before the thesis defense are offered during this workshop (and adapted to climate research): ethics, open science, sustainable development. The program also included a scientific seminar, presentations and discussions with alumni and a presentation of the innovation and entrepreneurship programs proposed by universities (Sorbonne University team in 2022).

IPSL also provided support to shared courses for doctoral students (e.g., radio workshops "Le climat est dans Laplace" in collaboration with ICOM).

Action 5. Renewed learning methods

This action aims to develop active teaching practices (learning by doing, e-learning, field and modelling courses, etc.) that promote the learning of climate science students. Since 2019, 68 projects were funded through the call for proposals, many dedicated to the development of innovative and practical learning tools (online climate modeling projects, for mediation or teaching, problem-based learning, e-learning courses and resources…). Some examples are detailed on the dedicated web a-page: https://www.ipsl.fr/formation/linnovation-pedagogique/

Activities in 2022-2023.

- The project e-course for masters for the development of 7 full online courses (3 ECTS) was continued, including the development of contents by the teams leading each course with continued advising by the educational engineer, the development of custom illustrations, videos, the continued development of the IPSL moodle LMS and the update of the IPSL channel on CanalU (for video streaming).
- A training is organized in collaboration with the IPSL ESPRI team to promote the use of the IPSL Jupyterlab environment for the construction of active learning using numerical notebooks.
- Projects proposed to the open call allowed the renewal of courses in different programs (e.g., courses for the online master "Climat & Média", construction of an experimental project at ENS) and the support for the writing of an educational book.

Action 6. Mentoring and alumni community

This action aims to improve the reception of students, particularly foreign students, to strengthen their sense of belonging to a community, their network and to progressively create an alumni community.

Activities in 2022-2023.

- A first IPSL student community event was organized in November 2022, "Keep in Touch" event:
  https://www.ipsl.fr/article/keep-in-touch-le-1er-rdv-alumni-de-lipsl-climate-graduate-school/
  It included two parts: (1) Presentation of the IPSL-CGS and presentations by students and graduates on their career paths, (2) open discussion and networking around a cocktail reception. This type of event meets an important demand from students, and will therefore be repeated.
- At doctoral level, the annual workshop "Journées des doctorants" also allows PhD students to better understand the thematic contours of IPSL and to feel surrounded by a close scientific community.
- Work has been undertaken to compile resources to support new students on their arrival in one of the Masters programs or laboratories. It will be formatted and made available online.

Additional projects.

Funding has also been dedicated to support scientific mediation (e.g., Climat TicTac video game), actions to train the trainers (support to OCE (Office for Climate Education), also linked to Action 2, or the "Prof en Fac" project) and communication actions to highlight education master programs and employment opportunities. These efforts are important and strategic for IPSL, both in terms of impact on society and in terms of strengthening the visibility of its activities (training and applied research in particular). We would therefore like to see the creation of a new action dedicated to scientific mediation, which would be co-supported by the training and research components.

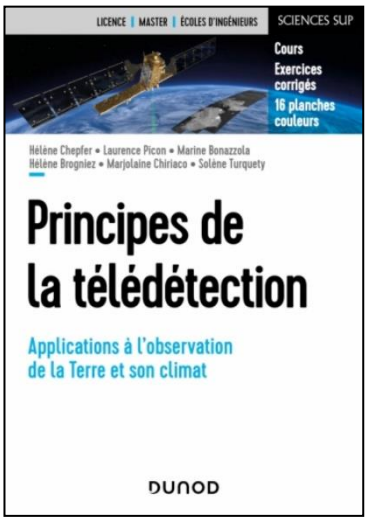
Limitations encountered, threats and opportunities.

The project had to face two main difficulties:

1. The end of the EIT support to the Climate KIC educational activities, and as a consequence the end of the international "Climate Leadership Journey" which was proposed to the IPSL associated masters and doctoral schools (20 participants selected in 2022).

2. The progress of e-courses has made significant progress this year, as mentioned above (actions 1 and 5) but has also faced delays. The heavy workload assumed by the teacher-researchers slowed down the construction of the educational scientific content during the past years. Beyond the payment of additional hours, the funding in 2022-2023 of “service time” (allowing a small reduction of in presence teaching time) has been instrumental in allowing colleagues to free up time to work on the project. It is essential to relieve the contributors in order to maintain the commitment of colleagues and to allow a dynamic activity for pedagogical innovation.

Highlights



One of the highlights of 2022-2023 is the finalization of the educational book “*Principes de la télédétection: application à l’observation de la Terre et de son climat*” dedicated to satellite remote sensing applied to climate sciences, to be released in June 2023 (Ed. Dunod, collection Science Sup, 352p.). The book writing was supported by the EUR IPSL-CGS (funding for proofreading by master students and secondary school teacher, “temps de service” for the co-authors) in the framework of Actions 1 and 5. The project was initiated in 2019, led by H. Chepfer and L. Picon, professors at SU, researchers at LMD, and co-written by researchers and lecturers in different laboratories and universities of IPSL (LMD, LATMOS; Sorbonne Université, UVSQ).

The book is dedicated to undergraduate and graduate students in scientific major (physics, mathematics, data science, engineering, climate science, remote sensing). It includes fundamental physical principles of remote sensing, the introduction of key elements of a satellite mission, as well as five chapters describing applications for the observation of the Earth's climate system. MCQs and corrected exercises allow the student to review the acquisition of knowledge. Online additional material includes corrected exercises and testimonies from experts.

The IPSL Virtual School

Since 2020, the IPSL Climate Graduate School has been organizing an annual spring or summer school on a specific theme related to climate change. This event is dedicated to international undergraduate and scientific masters' students who are passionate about climate sciences and wish to pursue a research career in Climate and Environmental Sciences in France, specifically in one of the IPSL-associated laboratories.

The first IPSL spring school was held online from July 1st to 3rd, 2020. The school focused on the theme “Climate Change: Challenges and Issues for the Earth Sciences”. It brought together approximately 50 students from 34 countries and featured 26 speakers, including PhD students from the laboratories, master's, and doctoral schools of the EUR IPSL-CGS and its partners.

In 2021, the 2nd IPSL virtual school was titled “Climate Change: Challenges and Issues for the Earth Sciences • Earth Observations and Their Use”. It was also conducted online from May 4 to 7, 2021. Around 50 students from 23 countries participated in this school, where they engaged in discussions with 22 researchers and 12 PhD students from various IPSL-associated laboratories.

In 2022, the 3rd edition of the IPSL virtual school was titled “Climate Change: Challenges and Issues in Data Sciences”. It took place online from May 16 to 19, 2021. Approximately 25 students from 11 countries enrolled in this school and interacted with 15 researchers and over 10 PhD students from different IPSL-associated laboratories.

This year, the 4th edition of the IPSL Virtual school will be held online from Paris, taking place from June 26 to 29, 2023. The principal theme for this year's school is “Climate Change: Challenges and Issues for the Water Cycle”.

For more information on the IPSL virtual schools, please visit:
https://www.ipsl.fr/en/education/ipsl-cgs-virtual-school/


Centers
and
services
5

Climate Modeling Center

Leaders
Masa Kayegama • Olivier Boucher

The CENTER in a nutshell

The main activities of the IPSL Climate Modelling Centre are articulated around:

- the development of an integrated model of the Earth system and of its major components;
- the achievement of climate simulation and the distribution of their results;
- the analysis of past, current and future climate variability and changes;
- the development of modelling techniques.

IPSL CMC brings together the different teams of the IPSL laboratories that have climate modelling activities but has also dedicated staff to develop the IPSL integrated model of the Earth system. Altogether CMC involves more than 80 engineers and scientists from LMD, LATMOS, LOCEAN, METIS and LSCE. A larger group of about 200 people in IPSL use its results and benefit from the availability of the simulation data.

IPSL CMC is currently involved in the ESM2025, 4C and OptimESM European projects. It was instrumental in building the TRACCS national research programme on climate modelling and climate services which had its kickoff in March 2023. It is also part of the CLIMERI-France research infrastructure. We have a presence in CMIP through participation in three different task force (model documentation, model data, climate forcing) and membership to the CMIP panel.

Beyond the analysis of available climate simulations on specific scientific questions, IPSL CMC is involved in a number of research directions aiming at (i) improving its Earth system model, (ii) better characterizing parametric uncertainties in climate models through model tuning, and (iii) complementing the traditional physical approaches with ML techniques and adapting its numerical models to the next generation of supercomputers.

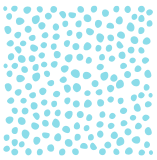
IPSL CMC is also heavily involved in training through a number of activities:

- Teaching activities using the LMDZ atmospheric model in university courses;
- Teaching classes in several masters of the Île-de-France;
- Annual doctoral school on “Numerical modelling for atmosphere and ocean” held in Brest, Grenoble or Paris;
- Annual training on the model components: LMDZ, ORCHIDEE, NEMO-PISCES;
- Annual training on the coupled model environment.

Activities

IPSL CMC is engaged in various activities aiming at improving the capability of its Earth system model.

- Development of a lower resolution climate model based on NEMO v4 for paleoclimate applications;
- Development of a LMDZ-Dynamico-NEMO v4 climate model that will form the nucleus of IPSL-CM7;
- Development of various Earth System modelling components: permafrost, nitrogen in vegetation, interactive CO_2, biogeochemical couplings between the



atmosphere and the ocean (e.g., DMS, OCS, N fluxes) and between the atmosphere and the vegetation (e.g. N fluxes);
- Improvement in the coupling scheme between the ocean and the atmosphere.

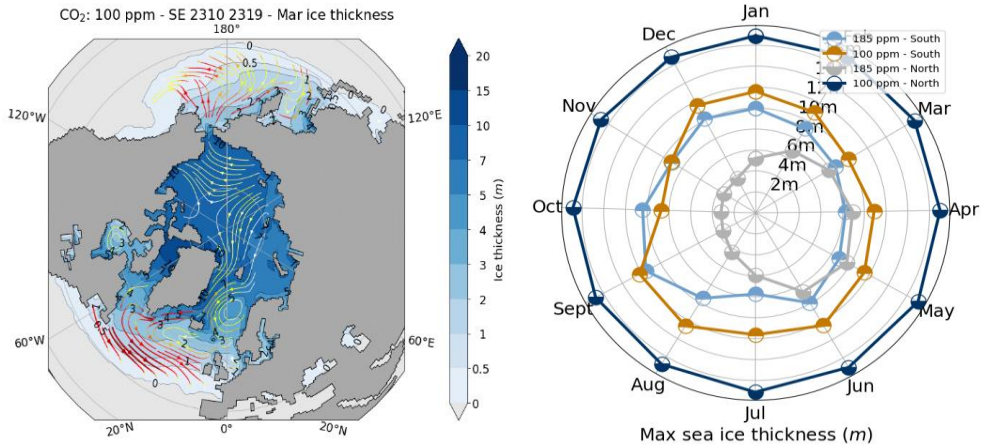
The tuning activities have become more systematic:
- When incorporating new parametrizations in the model (e.g. new radiative transfer scheme, ice supersaturation);
- By using zoomed and nudged simulations to confront observations at site level;
- By considering fast processes in the ocean (e.g. through sea ice parameters) to tune the coupled OA model;
- By incorporating new targets in relation to the ocean and the vegetation.

Nudged simulations have been designed and carried out to compute and diagnose the mean error terms of the model. Such an error term can then be reinjected in the model as a "weak" nudging term. It has been shown that such a procedure goes a long way to reduce systematic biases of the climate model, thus proving a useful technique to produce more robust climate change projection. Nudged simulations are also useful to understand why climate models fail to reproduce current trends in heatwave intensity over Europe.

The challenge is now to integrate together the various strands of model development which have flourished since the end of CMIP6. The current pre-IPSL-CM7 configuration based on the new atmospheric dynamical core and NEMO v4.2 currently suffers from important atmospheric biases at mid- and high-latitudes for reasons that remain unclear. A tuning is underway to check to which extent it can be corrected through a better choice of surface and atmospheric parameters. We currently concentrate the efforts to integrate a number of developments in ORCHIDEE v4. In parallel we investigate how the tuning methods that have been developed for the atmospheric model can be extended to the coupled OA model with targets that are relevant for the sea ice and the AMOC.

Highlight

IPSL-CM6A-LR and subsequent IPSL-CM6 configurations were not capable of simulating glacial climates because of an artificial build-up of sea ice that could reach 800 meters in a few centuries and would never stabilize. NEMO v4.2 and its new sea ice model (Sea-Ice Integrated Initiative) have been tested in a preliminary version of IPSL-CM. In order to test the robustness of this new configuration, we ran the model with atmospheric CO_2 concentrations of 180 and 100 ppm but with contemporary boundary conditions (i.e. without the surface albedos of ice caps in a cold climate). For the latter value of 100 ppm (which compensates for the lack of ice caps), the climate cools by 5°C which is consistent with a glacial climate. The model builds up a sea ice cover with maximum thicknesses of about 20 m. This thickness stabilizes within a few decades, indicating that the model is now robust (Figures below). We also successfully ran the model with a quadrupled CO_2 concentration to test its robustness in a warm climate.



Left: Sea ice thickness and velocities in March in an experiment with CO_2 concentration of 100 ppm. Right: Seasonal cycle of the maximum sea ice thickness for the two hemispheres and CO_2 concentrations of 185 and 100 ppm.

Main Publications (100% Open Access)

The CMIP6 exercise led to about 100 publications with an IPSL scientist in the author list over the period 2020-2023.

See the full list at: https://cmc.ipsl.fr/cmip6_publications/

Climaviation

IPSL-CMC is also heavily involved in the IPSL Aviation-climate progrgam, “Climaviation”, which aims at studying the climate impact of aviation, from better quantifying its current impact to assessing proposed solutions like contrail avoidance or sustainable aviation fuels. The project is a partnership between IPSL and ONERA, the French aerospace laboratory. Climaviation is finishing its second year, and the IPSL team now brings 12 researchers working on CO_2 emissions, contrail observations and modelling, atmospheric chemistry, and aerosol-cloud interactions. Among recent highlights, a representation of contrails has been added to LMDZ; simulations with LMDZ-INCA have revised the impact of aviation NO_x on climate and air quality; LES simulations found that aerosol perturbations of cirrus cloud only have an impact when they happen during cloud formation; and that different CO_2-equivalence metrics give widely different views of the climate benefit of contrail avoidance.

Earth Observation Center

Leaders
Martial Haeffelin · Hélène Brogniez

The CENTER in a nutshell

Major challenges for Earth observation.

- Studies and monitoring of land surfaces, oceans, atmosphere, biosphere on a global scale: define, select and finance satellite missions;
- Small-scale process study from detailed in-situ measurements: prepare and deploy field campaigns worldwide;
- Understanding climate variability and extremes: designing, operating, maintaining surface observation networks for several decades;
- Technological challenges: from innovation to robust/industrial solutions;
- Tracing of the quality of the measurements: standard protocols for observation, calibration, quality control;
- Data management, manipulation, processing: apply FAIR principles.

The objectives of the IPSL Earth Observation Center (I-CEO) are:

- Identify axes of coordination with a significant unifying character
- Conduct this coordination to advance more effectively in the understanding of the "climate system". The areas of work concern:
  - Coordination: development of common strategies
  - Visibility: through the activities of the IPSL and the Laboratories
  - Science: involvement in the strategic themes of the IPSL
  - Tools/methods: data, analysis, instrumentation, logistics...

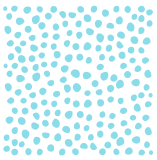
I-CEO includes **5 working groups** that support coordination activities in the following domains:

- IPSL Space group (coordination: **Hélène Brogniez**);
- Long-term observation infrastructures / observatories group (coordination: **Martial Haeffelin**);
- Urban environments group (multi-coordination: **Valérie Gros**, **Gilles Foret**, **Simone Kotthaus**);
- Analytical geochemistry platform group (coordination: **Arnaud Dapoigny**);
- Data analysis method group (coordination: **Jean-François Ribaud**);
- and is supplemented by a direct link with ESPRI, called ESPRI-OBS (coordination: **Sophie Cloché**) for data management.

Summary of the activity of the 5 years. In 2021, the SIRTA observatory moved to a new high-quality infrastructure on the campus of Ecole polytechnique to guaranty the capacity to operate in a sustainable work environment that is compatible with national and European roadmaps for research infrastructures, and with on-going and planned research and teaching projects.

- Successful, mostly seamless, move of all instruments to the new facility,
- 50 events (meetings, workshops, conferences) organized and hosted at SIRTA observatory per year,
- 40 teaching sessions (field work, hands-on training, student projects, training schools) organized at SIRTA observatory per year, hosting 400 students.

I-CEO supported 10 national and European projects deployed in the Paris region to study the urban atmosphere and urban environment under the umbrella of the



PANAME initiative by (1) designing a common and optimal observing network through synergies between the projects and (2) designing a comprehensive data portal under development by the AERIS data center: https://paname.aeris-data.fr

Following this initiative of ICEO, an "Urban Environment" group was launched in 2022, as a dedicated transverse scientific theme of IPSL, which highlights the growing importance of this research within IPSL.

A group on advanced analysis methods was intiated by ICEO. A major achievement of the group is a 20 year+ multi-parameter harmonized dataset based on SIRTA observations and other observed data in the Paris Region. The methodology developed is applied to develop other long-term multi-parameter datasets from data at other French and European observatories.

An I-CEO steering group has been created (1st meeting in January 2022), to discuss I-CEO actions and strategies. This steering group meets 3 times per year and is composed of 14 members covering the laboratories, the tools, the analysis methods and the scientific themes of the IPSL.

Concerning communications, the SIRTA website was completely redesigned to match current website standards, and to be consistent with the IPSL website: www.sirta.ipsl.fr

A similar work has been initiated for the I-CEO website.

Main orientations.

1. **Space.** Help IPSL researchers to prepare future space missions.
2. **SI-SNO-IR.** Support long-term observations on SI, SNO and in IR framework. Support synergies across domains. Clarify links with Paris region OSU on this topic.
3. **Urban.** Support research developments on the urban environment through network design, synergies on instrument deployment and operation, and dedicated data portal.
4. **Campaigns.** Define possible support by I-CEO and ESPRI-OBS for field campaigns.
5. **Platforms.** Support organization of data management for analytical geochemistry platforms.
6. **AI.** Provide support for innovative analysis methods.
7. **Web.** Develop I-CEO web site.

Activities (2022-2023)

In June-July 2022, 4 different field campaigns were conducted simultaneously in the Paris region to study urban climate and meteorology and related impacts on human health (H2C project), to study atmospheric chemistry accounting for both anthropogenic and biogenic emissions (ACROSS project), to study the specific emission of trees in the urban environment on emissions of Volatile Organic Compounds (VOCs) (STREET project), and finally a transverse project focusing on better characterization and understanding of atmospheric dynamics variability in the urban environment (DYNAMICS project), which has impacts on all three scientific topics mentioned above.

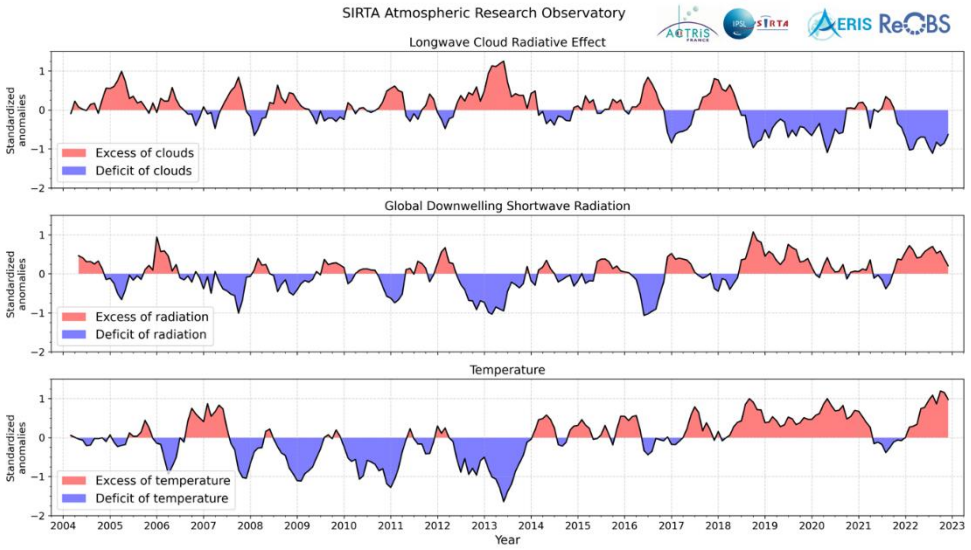
The IPSL website provides texts and videos presenting the projects:
https://www.ipsl.fr/campagne/paname-2022/

Planning of intensive observation periods were supported by a forecasting team, common to all 4 projects. Several heat waves and high pollution episodes hit the Paris region during the June-July 2022 period, providing all projects with ample recordings of scientifically relevant phenomena.

Preliminary results concerning the Paris region pollution plume, the Paris summertime urban heat-island effect, and the effect of hydric stress on trees are already on the IPSL website:
https://www.ipsl.fr/article/paname-2022-premieres-observations-dune-campagne-de-mesure-inedite-en-plein-paris-et-en-region-parisienne/

Highlight

20 years time series of standardized anomalies of Cloud radiative effect (proxy for cloud cover), downwelling Solar irradiance and 2-m air temperature observed at the SIRTA observatory. Several periods during the two decades show negative anomalies in cloud cover, leading to excess incoming solar irradiance, and resulting positive temperature anomalies (e.g. from mid-2018 onwards). Conversely, a positive cloud cover anomaly is found in 2012-2013 leading to a deficit in solar irradiance and negative temperature anomalies.



Main Publications (100% Open Access)

Publications linked to ICEO are flourishing but it's still difficult to present a full inventory. The renewing of the ICEO website has already started and there will be a page for the publications. A lot of publications can be found on the SIRTA website, regularly updated: https://sirta.ipsl.fr/publications/

Data and computing services (ESPRI)

Service managers
Sophie Cloché · Guillaume Levavasseur · Karim Ramage

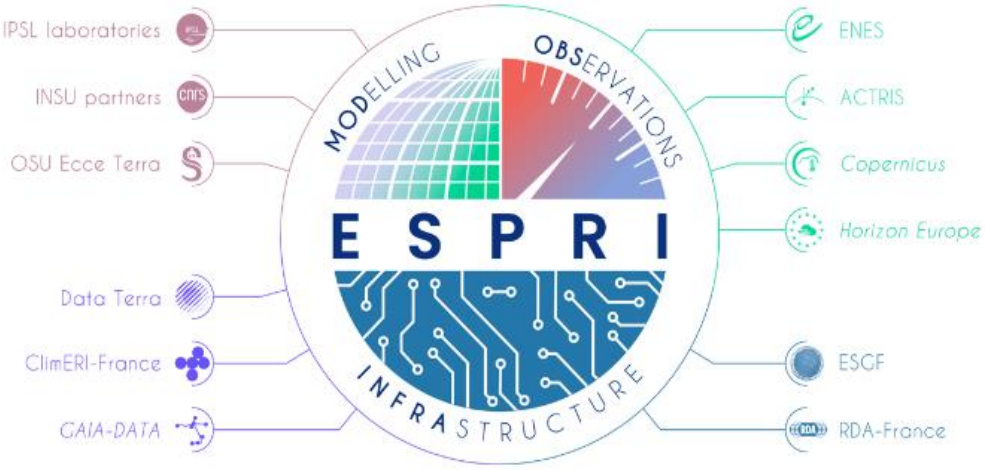
The IPSL Data and Computing services (ESPRI) in a nutshell

The IPSL Computing and Data Centre, also called "ESPRI", is in charge of system and network administration and the life-cycle of data from the IPSL Climate Modelling Center (CMC) and Centre for Earth Observation (CEO). ESPRI unit covers various fields such as data acquisition or production, data archiving and distribution and support of multidisciplinary projects carried out at IPSL. For 20 years now the IPSL data services organize the access for the IPSL laboratories and their partners, to different observational datasets as well as numerical simulations into a central data repository infrastructure, easily accessible along with HPC computing facilities to make data analysis easier.

The ESPRI service centralizes many different data products of interest for the earth-science community (satellite products, ground-based dataset, operational analyses and forecasts, climate model simulations). Thus, ESPRI engineers harmonize the development of a mutualized and multi-site data analysis platform and work in close relationship with scientific teams, allowing to understand and ton take into account their requirements efficiently. To support the activities of data management, processing and dissemination, ESPRI has developed an IT infrastructure which combines massive, high-performance storage and computing resources. This infrastructure, distributed on the sites of IPSL-SU and IPSL-Polytechnique, provides data managers and users with the hardware and software tools required for the exploitation and dissemination of data.

At national level, ESPRI plays a key role in the national research infrastructures DATA-TERRA (for the observation data management and access) and CLIMERI-France (for the production, analysis and dissemination of climate simulations, in close interaction with the international activity of the WCRP and the various users of these simulations).

In Europe, ESPRI acts as part of the infrastructure for the European Network of the Earth System modelling project (IS-ENES) by coordinating with European data centres (BADC - UK, DKRZ - Germany, CMCC - Italy). In addition, ESPRI strongly sustains the European Copernicus Programme through 6 C3S contracts (Copernicus Climate Change Services). ESPRI is also involved in the ACTRIS-DC as a part of the European consortium to handle the ACTRIS data.



Major structuring projects (international, EU, national) and national/international collaborations.

Opportunities and limitations. ESPRI is increasingly sollicited for data access and expertise sharing services from academic and non-academic organisations. This new mode of production must not take away from ESPRI's main mission of supporting climate research. Moreover, moving from a "best effort" mode of operation to a platform with "operational" services requires broader recruitment in several areas: "intelligent" data production (observation data and modelling data), qualification and availability of these data, methods for analysing large volumes of data, statistical modelling and climate science. It will also be necessary to develop services to enable users to take control more directly, or even to involve them in determining the actions to be taken on certain data sets (e.g. curation). Data-related jobs are very broad and currently poorly qualified within the public service, and are summarised in the terms "Data Manager" and "Data Scientist". The salary gap with the private sector, for equivalent skills, is also a major obstacle to the recruitment of specialised profiles (particularly for fixed-term contracts but also for statutory posts).

Despite these difficulties, in the coming years, the services developed by ESPRI aim to implement a "Data and services infrastructure for environmental and climate observation and modelling" integrated into the national system resulting from the GAIA DATA project. The objective is to enable distributed and transparent processing of multi-source remote data (observations or simulations) on a cloud-type infrastructure built around eight "backbone" centres and through several cross-cutting services based on international standards (W3C, OGC, CEOS, RDA, GO FAIR) with real technical and transdisciplinary interoperability. ESPRI is identified as one of these 8 centres and will play a major role in the convergence of Earth system observation and simulation data infrastructures.

Main orientations.
As explained before, at the national level, ESPRI will design and support the GAIA-DATA infrastructure. ESPRI staff participates in the GAIA-DATA work packages that will structure a large part of the ESPRI roadmap and developments until 2029. Five working groups have been created into ESPRI for spreading workload, developing synergies and fostering commitment.

Activities (2022-2023)

Several improvements to the ESPRI computing and storage center were finalized in 2022-2023. Specifically, a new generation of computing cluster went into production in September and two JupyterHub services were deployed to meet the needs of research and teaching.

Regarding our support to IPSL projects, two pilot databases will be finalized and delivered, one on paleoclimate observations and the other on GIS applications for Project on permafrost. We will also have to ensure the sustainability of these developments. ESPRI is also in charge of the development of the catalog and database of the PANAME initiative related to the study of urban climate and air pollution. A fixed short-term contract has been be recruited.

Regarding our activities linked to AERIS, ESPRI will also start its activities in the ACTRIS-Data Center as a part of the European consortium to handle the ACTRIS data. Finally, ESPRI is involved in the definition of a roadmap for a global service offering tool around operational support to measurement campaigns, in the framework of AERIS and DATA TERRA.

ESPRI also continued to significantly contribute to European project IS-ENES3 (end in April 2023) and will stay the coordinator of the infrastructure providing climate projections for the Copernicus Climate Change Service.

In 2022, IPSL additional resources have been allocated to develop the climate services activities to meet growing demand. In such a context, ESPRI is developing a bias correction workflow for climate simulations and support scientific application with the South countries in strong collaboration with the Institut de Recherche pour le Développement (IRD).

Finally, ESPRI is now involved in the CMIP7 Task Teams that started designing the infrastructure and data services that will serve CMIP7 exercise. For instance, ESPRI proposed to deploy a Controlled Vocabulary service next to the Errata Service developed in 2016 and put into production in 2018. Such a service has been approved the WCRP Infrastructure Panel.

Highlight

In 2022, ESPRI implemented virtual research environments and developed engineering activities around AI aim to meet the needs of both research and digital teaching activities based on IPSL tools (models and data). We organized a 2-days workshop with all ESPRI engineers that lead to a very fruitful documentation plan. Since then, ESPRI services are being documented on the new ESPRI website:
http://espri.ipsl.fr/

Communication & Mediation

Service manager
Marie Pinhas-Diena

The IPSL Communication & Mediation Department (ICoM) in a nutshell

The objectives. Communication and mediation are keys to a proper understanding of climate science and climate issues from the large public and stakeholders. The IPSL Communication & Mediation Department (ICoM) defines and implements a strategy of communication actions (institutional, internal, external and digital) and mediation to promote, at national and international scales, all of the IPSL's activities (research, training, innovation/transfer of expertise). It designs and organizes large-scale operations and events and produces resources for a wide and diverse audience (pupils, students, stake holders, political and economic decision-makers, media…). ICOM is constantly mobilized to respond to numerous requests (internal and external) and to involve the entire IPSL community in this adventure of disseminating knowledge. It also carries out a watch on tools, practices, graphic trend, on science (scientific production, publication of results…) and on media (information processing, new media…). Mediation at IPSL can take many forms: laboratory visits, hosting pupils, students and trainees, communication about scientific campaigns, responses to invitations and/or requests for presentations (schools, high schools, media, associations…), participation to major events such as La Fête de la Science, le Forum International de la Météo et du Climat…

Current status of the service. ICOM operates under the responsibility of the institute's director and works in close interaction with the 8 IPSL member laboratories and 2 associated teams and their supervisory authorities. 4 persons are working at ICOM: Marie Pinhas-Diena (communication manager, permanent), Isabelle Genau (communication assistant permanent), Tiphaine Claveau (communication officer, non-permanent SU 2021-2023) replaced by Daniel Peyronel (communication officer, non-permanent SU since 2023) and Gaëlle Porte (communication officer, non-permanent CNRS since 2023).

Building a sustainable communication strategy for the IPSL. Climate sciences are a major and mobilising field subject to strong media exposure. It is essential to define a global and interdisciplinary approach to communication, dissemination and interaction with society. The IPSL's communication strategy aims to:

- Set out the main strategic orientations;
- Give a modern image of creative and constantly renewed research;
- Publicise the expertise and services offered by the IPSL;
- Position itself as a player in high-level education and training with a wide range of opportunities;
- Raise awareness among all types of audiences and players, from the most informed and knowledgeable to the least receptive and committed;
- Show the driving role of the teams at international level and in the concert of nations (IPCC);
- Participate in the “science and society” dialogue (new insights, different levels of reading, a mix of information processing methods).

The graphic design of the logo and **refreshment of the visual identity of IPSL** correlated to the **renovation of the website** since 2021 gives more visibility to the dual laboratory/IPSL membership. This pairs with a **graphic strategy** also called visual communication (graphic charter, logotype, signage, web design, etc.) arousing interest by appealing to our sensibilities. The colours, typography and illustrations used on the various communication media (website, social networks, flyers, posters, etc.) bring coherence to the communication and generate commitment, particularly on social networks. Consequently, the **development of a coherent and well-thought-out digital strategy** since 2020 (Social media campaign, Twitter, Facebook, Instagram, LinkedIn, YouTube…) based on an analysis of the highly fluctuating social media landscape contributes to relaying all the information coming from the laboratories to different audience, such as the Alumni.

Opportunities and limitations. The team lacks human resources to achieve all these projects, especially communication officers or correspondents in the labs.

Main orientations. ICOM started to reorganise the service and planned a new form of communication strategy. With the concept "IPSL: Laplace to be", ICOM aims to develop and foster the emergence of science-society links on climate change through interdisciplinary scientific projects, establish climate services as a new scientific issue, and develop the emergence of climate research applications outside the academic sector in the field of climate change. This project by and for the IPSL aims to be part of the "science and society" dialogue by offering new insights and different levels of reading. This project should expose the main strategic orientations, give a modern image of what creative research is, both tried and tested and in perpetual renewal. ICOM also plans to promote the expertise and services offered by the IPSL to elected representatives and political and economic decision-makers and stakeholders. Over the years, it will help IPSL to position itself as an actor in high-level education and training. The repatriation to the IPSL and the redesign of the website "Le climate en questions" will be at the heart of the system/serve as a basis for this evolution.

ICoM regularly participates and takes important part into public events such as the annual Fête de la Science or the International Forum on Weather and Climate, science bars, and arranges school visits. ICoM plans to diversify the event formats and extend them to more diverse audiences including socio-economic actors, decision-makers, elected representatives, and opinion leaders…

Main projects.

- The launch of a season 2 of the podcast "Le climat, une question de…": a podcast with two speakers;
- The launch of "IPSL News": podcasts news explained by IPSL/ The IPSL's view on news;
- A partnership with Radio Campus Paris: introduction to broadcasting for IPSL-CGS students;
- Mozaïka: a thematic of comic strips: "Ocean" (2021-2030, Ocean Decade); "Chroniques du changement climatique", novels; "mozAIka, AI, Arts & climate sciences"; "Urban climate"… https://www.ipsl.fr/decouvrir/mozaika/

- Update and enrich with news, videos and events and workshops, the web pages of each theme of IPSL Thema: https://www.ipsl.fr/recherche/les-thematiques-scientifiques (FR & ENG);
- "Join IPSL!": a campaign to make IPSL jobs offers more attractive;
- Relaunch of the Newsletter "Flash Infos";
- Developing a communication strategy for the EUR-CGS "Education";
- Create links and collaborations with external partners, for with Human Sciences Network/Labs;
- The redesign of "Le climat en questions" website: https://www.climat-en-questions.fr/

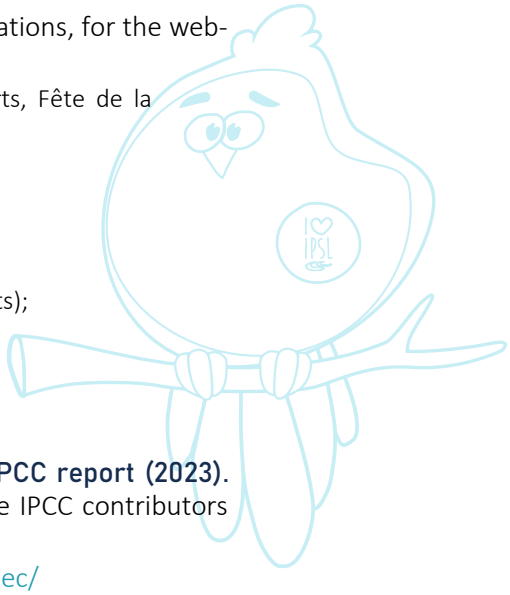
Activities (2022-2023)

The development of a coherent and well-thought-out editorial strategy is based on the work of communication and journalism writers, video makers and tailor-made visual storytelling.

The transfer and the redesign of the "Le climat en questions" website provides measurable added value from the point of view of image, referencing and interactivity. This website respects the graphic charter of the new IPSL website.

Graphic design and animated videos for different events, publications, for the website and social media:

- IPSL-CGS Virtual School, IPSL presentation of activities, reports, Fête de la science, IPCC Reports, COP, social media…
- **Creation of SPILOU, IPSL mascot.**



Mediation.

- Hosting pupils, students and trainees;
- Communication about scientific campaigns (notebooks, portraits);
- Fête de la Science;
- Forum International de la Météo et du Climat (Paris);
- Prof en Fac (high school teachers and university lecturer, Paris).

Editorial and graphic support for the publication of the 6th IPCC report (2023). "Regards intimes sur le GIEC": 8 portraits and interviews of the IPCC contributors (authors) from IPSL:
https://www.ipsl.fr/decouvrir/mozaika/regards-intimes-sur-le-giec/

Videos and podcasts.

- Podcast: "Le climat, une question de…" (11 issues);
- "IPSL: at the heart of climate science", corporate video of IPSL (FR, ENG): https://www.youtube.com/watch?v=lbiVncXgyuw
- "IPSL News": short videos to promote scientific news and/or events: https://tinyurl.com/4wytf65y

Mozaïka. A thematic of comic strips: "Chroniques du changement climatique" (novels); "Des orages plein les yeux"; "mozAIka, AI, Arts & climate sciences" ; "Regards intimes sur le GIEC" : https://www.ipsl.fr/decouvrir/mozaika/

Partnership with Radio Campus Paris. Broadcast workshop for IPSL-CGS students: different aspects of radio, from the use of equipment to producing and editing a programme. Creation of a unique radio show, “Recherche académique : indépendance TotalE”:
https://www.ipsl.fr/agenda/archives-evenements/live-radio-recherche-academique-independance-totale/

Graphic and editorial redesign of “Le climat en question” website.
Repatriation to the IPSL web platform. Thinking on the new editorial line:
https://www.climat-en-questions.fr/

Social media. The editorial line of the various social media of the IPSL has been reworked to increase the visibility of the IPSL and to reach an ever larger and more diversified public. The activity on social networks has been considerably expanded, guaranteeing a high visibility of the IPSL towards the outside world. The number of followers and subscribers has been multiplied. LinkedIn is used to build and strengthen the alumni network. The YouTube channel has been reorganised (editorial line and creation of thematic playlists). The Instagram and Facebook accounts have seen a new start with the creation of dedicated visuals and illustrations and the publication of stories to accompany the news, international days...

Highlight

On line News "Regards intimes sur le GIEC"

On the occasion of the publication of the 6th IPCC report in 2023, the communication service of the IPSL (ICoM) called upon the photographer Valérie Lilette to produce a series of photographic portraits of the eight contributors of the IPSL. The aim of this project was to highlight men and women who are committed both as scientists and as citizens. And in so doing, to show the major role of the IPSL community as a whole and its responses to societal issues.
https://www.ipsl.fr/decouvrir/mozaika/regards-intimes-sur-le-giec/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Laplace
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