IPSL

Activity Report

July 2021 • June 2022

Executive

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, this document reports the activities that took place in 2021-2022. A focus is put in particular on core activities (modeling and observation centers, data and computing services, communication and climate services).

During the last year, modeling teams have completed CMIP6 with a few foci, and further developed modeling in several directions with preliminary experiments using the new dynamical core. Both very low-resolution and high resolutions were explored, as well as novel techniques (eg. online bias correction). An in-depth thinking on the strategy to port model components onto GPU architectures has been conducted and its application has started. Observation teams have focused efforts on a number of aspects, including preparation of coordinated campaigns that will take place in Summer 2022 in the Paris region, the installation of key monitoring instruments, the development of the environmental analytic platform.

A specific effort has been put in coordinating initiatives in research on regional climate and air quality. The data and computing services (ESPRI) have continued to strengthen service elements, feeding support to centers and scientific themes. ESPRI was awarded the CNRS medal for the long-term effort and success in coordinating community services. The communication team has developed a portfolio of communication elements on climate science questions and climate change, in various formats, and was awarded the CNRS medal for mediation for the serious game “ClimaTicTac”. Climate services developed new partnerships and projects, among which a “regional science-society” group with focus on the Île-de-France Region, and started the strategic C3S project on climate projection provision. The research and training programs developed new scientific ideas along 8 research themes, with a focus to strengthen the training of Master and PhD students with attractive research topics and ideas.

This document also provides the key numbers for IPSL and an analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT) which will feed further developments, both in terms of program priorities and governance or institutional evolutions, to be discussed with the sponsoring organisations.

Summary

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IPSL objectives and activities

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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 67 staff, 40 of which are permanent and about 27 are on fixed-term contracts. In total, IPSL brings together about 1400 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 • https://www.cerea-lab.fr/
[2] Geosciences Paris-Saclay • http://geops.geol.u-psud.fr/
[3] Laboratoire Atmosphère, Observations Spatiales • http://www.latmos.ipsl.fr/index.php/fr/
[4] Laboratoire Inter-universitaire des Systèmes Atmosphériques • http://www.lisa.u-pec.fr/
[5] Laboratoire de Météorologie Dynamique • https://www.lmd.ipsl.fr/
[6] Laboratoire d'Océanographie et du Climat, Expérimentations et Approches Numériques • https://www.locean-ipsl.upmc.fr/
[7] Laboratoire des Sciences du Climat et de l'Environnement • https://www.lsce.ipsl.fr/
[8] Milieux environnementaux, transferts et interactions dans les hydrosystèmes et les sols • https://www.metis.upmc.fr/
[9] LERMA, TASQ team • https://lerma.obspm.fr/
[10] Laboratoire de Géologie de l'ENS, "Surface et réservoirs" team • http://www.geologie.ens.fr/

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 partners, 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.

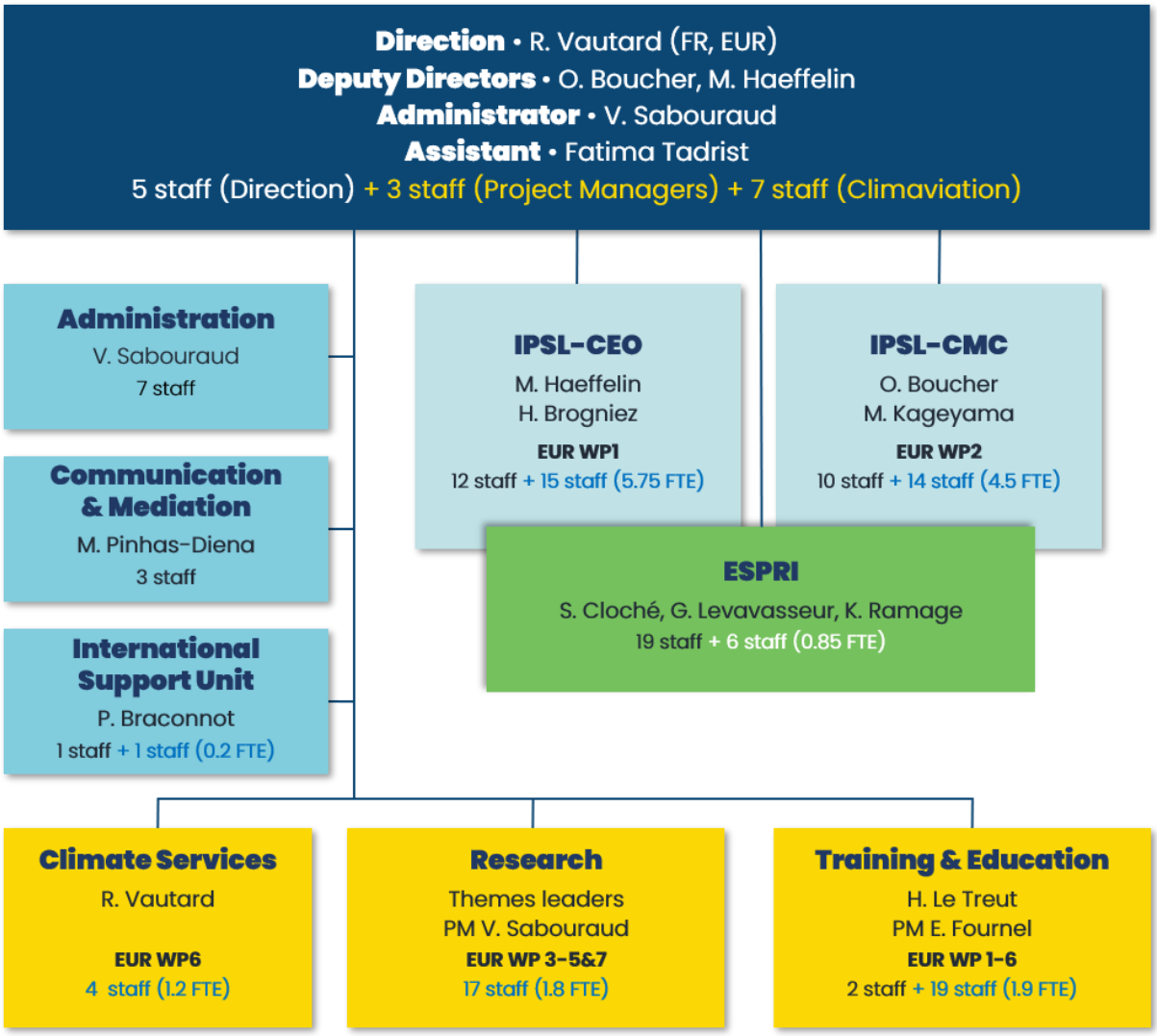
5. Data and computing. Develop and offer a set of regional, national and international IT services for research related to the storage and use of environmental and climatic data.

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, IPSL Climate Modeling Center, IPSL Earth Observation Center, ESPRI services, Communication and Mediation, Climate services and expertise 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 **67 staff (66 FTE) within FR IPSL** and **76 staff (16.2 FTE) outside FR IPSL**.

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 **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 Service and expertise (IPSL-CSE)** develops data and projects with several stakeholders (public and private) 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.

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;

The **research program** provides scientific coordination and resources along 8 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.

IPSL in numbers

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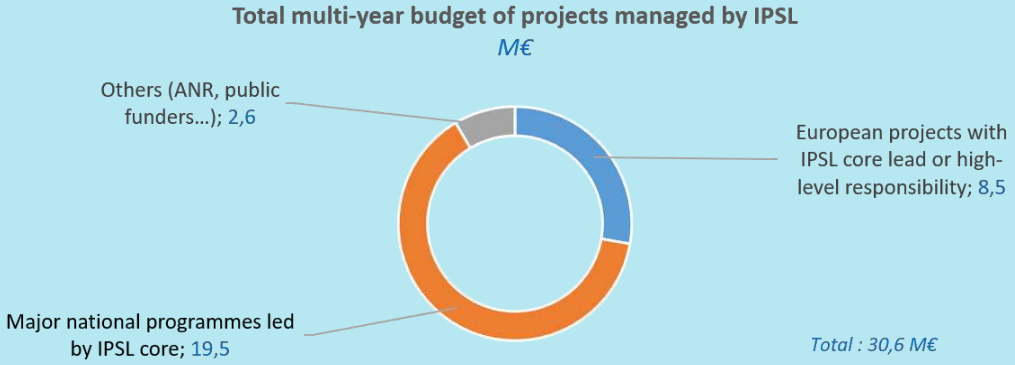
IPSL includes about 1400 staff. IPSL has a number of leading scientists in climate sciences, reflected by **8 scientists involved in the 6th IPCC cycle**. Valérie Masson-Delmotte (LSCE-IPSL) is one of the two co-chairs of the WGI, Sophie Szopa (LSCE-IPSL) and Robert Vautard (IPSL) are AR6 WGI Coordinating 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.

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). In 2021, several IPSL teams and researchers received an award: the mediation **CNRS medal** for the ClimaTicTac serious game, a **CNRS medal** for the ESPRI achievements. Agnès Ducharne (METIS-IPSL) was awarded with the French-Taïwan Academy price.

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
- 2 major national programmes led by IPSL core team (EUR IPSL-CGS and CLIMAVIATION)
- 19 other projects (ANR, public funders...)

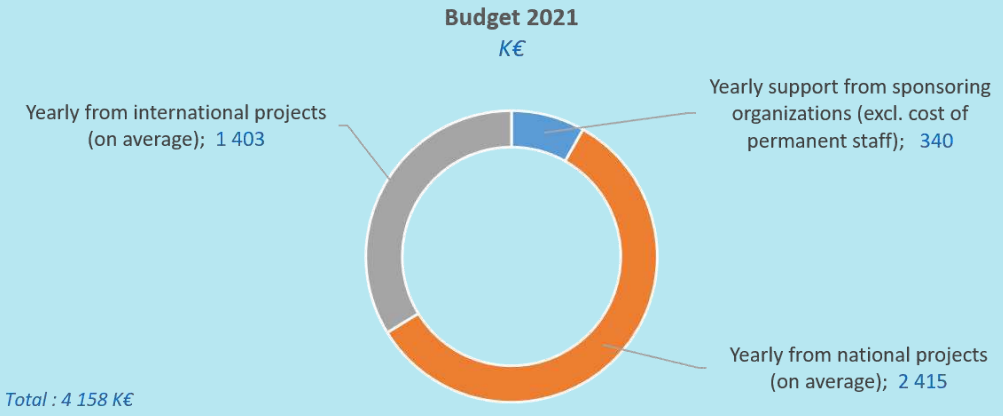


Human resources

- 68 IPSL core staff for coordination, centers and services
- 16,2 FTE additional effort to the collective from staff from IPSL research units
- 1400 total staff in IPSL

Annual Budget

- 340 k€ yearly support from sponsoring organizations (excl. cost of permanent staff)
- 3 818 k€ yearly from all projects (on average)
- 2 415 k€ year from national projects (on average)
- 1 403 k€ year from international projects (on average)



Summaries of activities

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Climate Modeling Center

Leaders

Masa Kayegama • Olivier Boucher

The Climate Modeling Center in a nutshell

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

- the development of an integrated model of the Earth system and of its major's 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 modeling techniques.

IPSL CMC brings together the different teams of the IPSL laboratories that have climate modeling 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.

We divide this annual report into two parts: a first part on the analysis of experiments in the context of a transition between CMIP6 and CMIP7, and a second part on the continued development of our climate models.

Activities - Period from July 1, 2021 to June 30, 2022

In 2021/2022, we continued the production of CMIP6 simulations albeit at a much slower pace (e.g., simulations from new climate-chemistry simulations, rerunning experiments with missing outputs for downscaling purpose). We have also analysed CMIP6 model results with a focus on PMIP: Last Glacial Maximum (Otto-Bliesner *et al.*, 2021), mid-Holocene (Braconnot *et al.*, 2021; Carré *et al.*, 2021) and late Holocene (Silvestri *et al.*, 2022). We have performed a range of high-resolution simulations with the atmospheric model, using both the old dynamical core (LMDZORv6 at 0.5° resolution) and the new DYNAMICO icosahedral dynamical core (IPSL-CM6A-ATM-ICO at 200, 100, 50 and 25 km resolutions). Model outputs are being analyzed further. However, a preliminary analysis shows that the highest resolution models are able to simulate tropical cyclones in cyclonic regions (see figure 1).

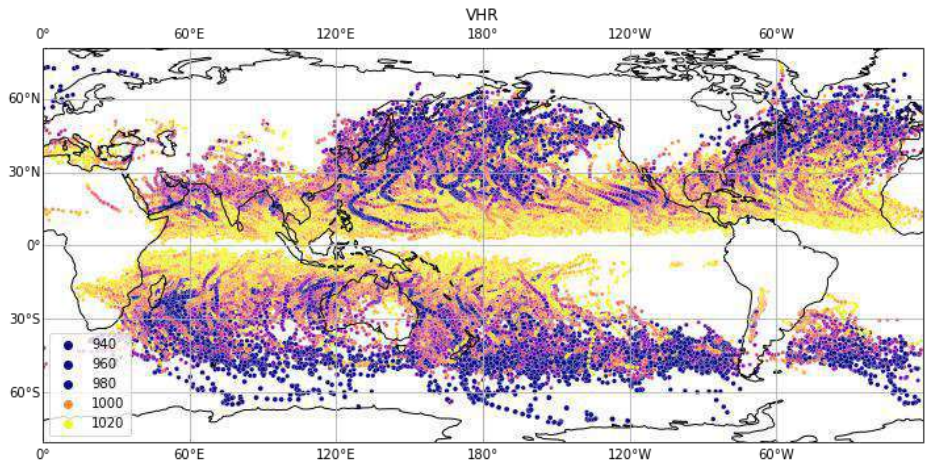


Figure 1. Density of trajectories of tropical and extratropical cyclones detected in a simulation with the very-high resolution (*i.e.* 25 km) configuration of the new atmospheric model with icosahedral grid (IPSL-CM6A-ATM-ICO) for the period 1980-2019.

IPSL-CM6A-LR is characterized by a relatively high internal climate variability as seen in the large ensemble of historical simulations that was performed for CMIP6. We have shown that members with the smallest rates of global warming over the past 6-7 decades, consistent with the observed one, are also those with a large internally-driven weakening of the Atlantic Meridional Overturning Circulation (AMOC). This subset of members also matches several AMOC observational fingerprints, which are in line with such a weakening. IPSL-CM6A-LR shows a decrease in the intensity of the AMOC in future projections and a decrease in the amount of interannual climate variability in some regions which is currently being analyzed further.

We have also contributed to VolMIP by decoupling the climate response due to surface cooling to that due from changes in stratospheric heating (Zanchettin *et al.*, 2022) and to GeoMIP by performing and analyzing various experiments that look at the climate response to stratospheric aerosol injection, in terms of stratospheric heating (Tilmes *et al.*, 2022), the NAO and the QBO (Jones *et al.*, 2022). In ScenarioMIP, our focus has been on the behavior of the carbon cycle in overshoot scenarios by disentangling the respective roles of carbon-climate feedbacks, land use change emissions (due to BECCS) and reforestation/afforestation.

Finally, new configurations with tropospheric (INCA) and stratospheric (REPROBUS) chemistry have been used to estimate the evolution of the stratospheric ozone layer or tropospheric chemistry and secondary organic aerosols under varying levels of VOCs.

In terms of model development, we have worked simultaneously on very-low resolution, standard and high-resolution configurations of our suite of climate models. IPSL-CM6A-VLR is the very-low resolution under development aiming at long and ensemble simulations of paleoclimates. A particle filter was implemented to “nudge” simulations towards observed proxies (Assim2k project). The QUEST configurations (IPSL-CM6A-MR1 and IPSL-CM6A-MR025) with a resolution of 256x256x79 in the atmosphere and either 1° or ¼° in the ocean are now available, and have been the opportunity to streamline further our procedure for model adjustment following our experience with IPSL-CM6A-LR (Mignot *et al.*, 2021). A version of IPSL-CM6A-LR with interactive CO_2 is now available with a very decent simulation of the increase in CO_2 concentration during the historical period. This version is now used for decadal prediction as part of the 4C European project. Tuning of new model configurations has further progressed using a “history matching” technique with “iterative refocusing” and a wider range of observational constraints based on LES simulations, observations at the SIRTA instrumented site and large-scale emergent constraints. This tuning technique has been used to produce model versions with equivalent skill against selected observations but different climate sensitivities. To automatize fully this tuning procedure for coupled models requires the development of techniques to speed up the spin up of the ocean model, which is currently being attempted using ML techniques to extrapolate the spin up state from the initial tendencies.

While IPSL-CM6A-LR scores better against various climatologies, some persistent biases remain. An on-line bias correction has thus been developed. First we estimate the time average of the nudging tendencies in atmospheric wind and temperature computed in a simulation nudged to a present-day reanalysis. Then this correction term is applied at every time step of the model in addition to an SST bias correction. This produces present-day climate

simulations with much improved statistics against observations and more robust climate projections for climate impact studies.

We have started to address the issue induced by asynchronous coupling between the atmosphere and the ocean by implementing the iterative Schwarz method to couple the two models and are now seeking a faster implementation through ML methods. We have also started to implement a simple model for river temperature in the ORCHIDEE river routing scheme. The reservoirs are initialized with the soil temperatures at different depths and the water energy content is advected along the river in a way that is consistent with the advection of water fluxes (see figure 2).

Another focus for 2022 and the coming years is to port our model components onto GPU architectures. Work has started on the LMDZ model with a strategy mixing some code restructuring and porting with OpenACC instructions.

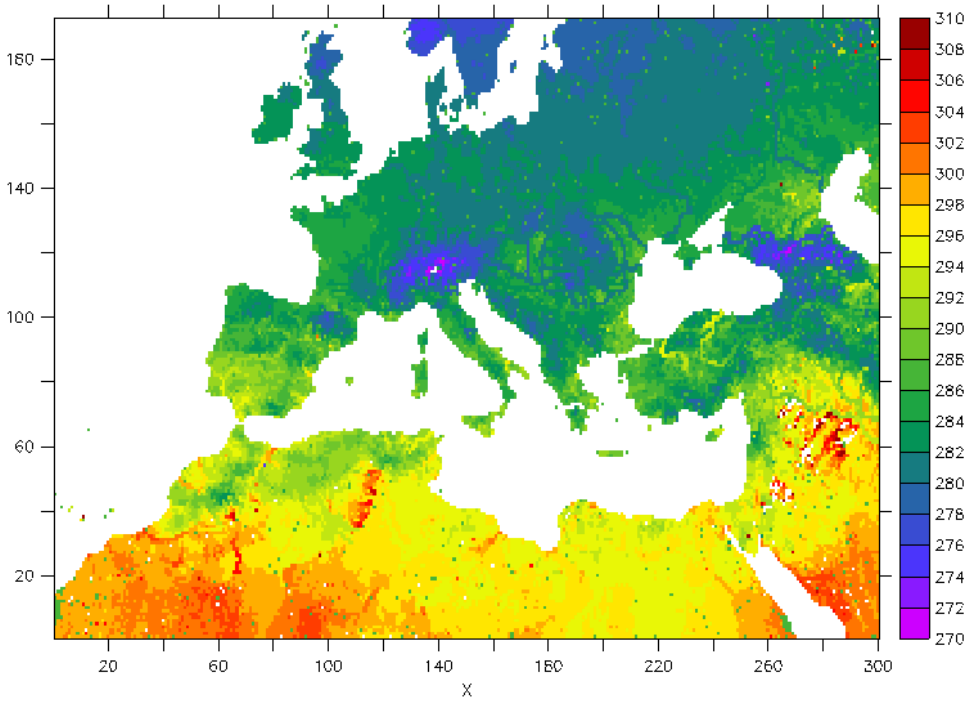


Figure 2. Example of river temperatures (in K) simulated in the ORCHIDEE routing scheme. Large rivers are visible with cooler temperatures than their surroundings. Preliminary results.

Earth Observation Center

Leaders

Martial Haeffelin and Hélène Brogniez

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 are to:

- 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...

IPSL CEO includes 6 working groups that support coordination activities in the following domains:

- IPSL Space group (15 PIs from LMD, LATMOS, LOCEAN, LSCE, LISA, and LERMA research labs involved in satellite missions);
- long-term observation infrastructures / observatories group (observation services dedicated to research on aerosols, reactive gases - in Europe and Africa, greenhouse gases - in the atmosphere and ocean, ocean temperature and salinity; and associated observation and experimental platforms);
- urban environments group (PANAME initiative developing synergies between 10 different national (ANR) and international (H2020, ERC) projects that focus on developing measurement systems, better retrievals of key atmospheric variables, model evaluation, physical process understanding, chemical process understanding;
- analytical geochemistry platform group;
- data analysis methods group.

Activities - Period from July 1, 2021 to June 30, 2022

IPSL Satellite Group (Coord. Hélène Brogniez)

The group gathers about 15 People that acts as scientific principal or co- investigators in satellite missions covering the following domains: atmosphere – greenhouse gases (Microcarb/Merlin), reactive gases (IASI/IASI-NG), aerosols, clouds, precipitation (ADM-

Aeolus, EarthCARE, AOS...); ocean temperature and salinity (CFOSAT, SMOS, SWOT...), continental surfaces and biosphere (FLEX). In February 2022, the IPSL Satellite group organized a meeting between IPSL satellite mission principal investigators and the French space agency CNES thematic experts that cover all topics of Earth studies. The IPSL Satellite Group produced two strategic documents: (1) Impact of CNES budget reduction on Earth observation scientific research; (2) IPSL position on future ESA Climate Space program.

Long-Term Observations Group via research infrastructures and national observation services (Coord. Martial Haeffelin)

IPSL-CEO is coordinating efforts in the construction of the ACTRIS (Aerosol, Cloud, Trace Gas) research infrastructure that concern measurement facilities (SIRTA observatory, https://sirta.ipsl.fr/), topical expertise centers for aerosols and for clouds (both centers hosted in the SIRTA observatory), and the French national atmospheric data center in which ESPRI plays a key role.

A major milestone of fall 2021 is the installation of the aerosol remote sensing Lidar and the cloud remote sensing suite of instruments (Cloud radar, microwave radiometer, ceilometer and Doppler Lidar) in the new SIRTA observatory building. SIRTA has thus been selected to be an ACTRIS pilot facility starting the ACTRIS labelling process in spring 2022. The new SIRTA observatory provides a high-quality and stable environment for atmospheric research measurements and experimental teaching at IPSL for the next decades.

Two new observation systems received a "national observation service" label from CNRS/INSU in 2021, (1) PEGASUS (PortablE Gas and Aerosols Sampling UnitS) a mobile multi-instrumented platform to study aerosol physical and chemical properties (operated by LISA) and (2) CLAP (CLimate relevant Aerosol Properties from near surface observations) an essential component of the ACTRIS research infrastructure in which LSCE and LISA laboratories are involved.

Urban Climate/Environment Group; focus Paris region (link in particular with the group on Atmospheric Composition and Air quality) – (multi-coord. Valérie Gros, Gilles Foret, Simone Kotthaus)

The urban climate group, working hand-in-hand with the IPSL Atmospheric Composition scientific theme (see Appendix 4.6), is pursuing several objectives. Scientific topics of interest to multiple IPSL labs were identified (e.g. life cycle of metals in the urban environment; biosphere in the city; dynamics of the urban atmospheric boundary layer).

The group launched an initiative called "PANAME" (for PAris region urbaN Atmospheric observations and models for Multidisciplinary rEsearch) in fall 2021 with the objective to promote collaborations and develop multi-project synergies among 10 different (national and international) projects that deploy new measurements in the Paris region. The objectives of the PANAME initiative are to:

- develop synergies on scientific questions and studies;
- design consistent measurement networks across the different projects;
- support activities concerning model development (Adhoc group starting up);
- setup a Data Portal with common data catalog, data vocabulary.

Information on the PANAME initiative can be found at https://paname.aeris-data.fr

Earth observation data analysis methods axis – (Coord. Jean-François Ribaud)

I-CEO is boosting its capacity to perform data analysis through application of innovative methods (e.g. artificial intelligence) with the goal to enhance our capacity to interpret large quantities of observed data and better exploit the synergies between multiple variables. The first three projects focused on (1) retrieval of geophysical variables from the IPSL Mutliwavelength Raman Lidar to provide aerosol optical property profiles in near real time, (2) analysis of trends, variabilities and anomalies of key climate variables over the Paris region (e.g temperature, precipitation, cloud cover and radiative effect, atmospheric boundary layer – ReOBS datafile) in the past 2 decades, (3) multi-variable analyses using machine learning approaches to enhance process understanding.

Analytical geochemistry platforms group – (Coord. Vincent Scao)

The PANOPLY platform provides the scientific, academic and industrial community with the range of high-tech resources of the Saclay plateau in the field of Earth, Climate and Environmental sciences. In addition to monitoring analytical services and communication, the dynamic of the platform has been structured since 2020 around 3 working groups, respectively on scientific and technical animation, support for innovation and development and management of research data. PANOPLY continued to support requests for equipment by creating new synergies around a common strategy on the renewal of analytical equipment (calls for projects, pooling).

Data and computing services (ESPRI)

Service managers

Sophie Cloché • Guillaume Levavasseur • Karim Ramage

The IPSL services, through the ESPRI unit, 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. For 20 years now the IPSL data services organize the access for the IPSL laboratories and their partners, to different observational datasets as well 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 them to understand and to 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-Sorbonne Université and IPSL-École Polytechnique, provides data managers and users with the hardware and software tools required for the exploitation and dissemination of data.

The data managed at the IPSL come from multiple sources and volumes: in situ observations, surface observations by remote sensing, satellite observations, database, data from digital experiments. The level of “service” provided by ESPRI for this data also varies significantly depending on the dataset. This can range from the provision of bare storage space (*i.e.* without any other associated service) to full support of the data life cycle within the framework of Data Management Plans developed on a national, European or global scale.

At national level, ESPRI plays a key role in the national research infrastructures (for the observation data management and access and 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 modeling project (IS-ENES) by coordinating with European data centres (BADC - UK, DKRZ - Germany, CMCC - Italy). A part of the ESPRI workload consists in operational implementation and key developments for the third phase of IS-ENES project. 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. ACTRIS is a Pan-European research infrastructure producing high-quality data and information on short-lived atmospheric constituents and on the processes leading to the variability of these constituents in natural and controlled atmospheres. The primary role of ACTRIS DC is to compile, archive and provide access to well documented and traceable ACTRIS measurement data and data products,

including digital tools for visualisations, data analysis and research. As a tool for science, the highest priorities for ACTRIS DC is to maintain and increase the availability of ACTRIS data and data products relevant to climate and air quality research for all interested users.

ESPRI is increasingly solicited for data access and expertise sharing services from academic and also for non-academic organisations (public and private). 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 a nationally organized environmental data management infrastructure currently in construction (called “GAIA DATA”). 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.

Activities - Period from July 1, 2021 to June 30, 2022

ESPRI continued hardware and software renewal of its computing infrastructure started in 2019. The final step of this renewal will be undertaken in 2022, with a complete upgrade of the software infrastructure (new OS, new job scheduling system, new versions of scientific software). At the end of 2021, ESPRI finalized a beta release of a “jupyterhub service” that intends to put into production in 2022 to enable new, simpler and interactive access to the computing and storage resources for data exploitation. Regarding storage, a new monitoring system has been deployed on all data spaces and user spaces.

At the end of 2021, 2 permanent positions were filled in the ESPRI team, 1 IRD position on climate services and statistical calculation and 1 position (CNRS) on the processing and management of observation data.

ESPRI has initiated during 2021 an international certification process, the Core Trust Steal. The application will be submitted before the end of 2022.

ESPRI started to support a new activity around GIS-formatted data. For this purpose, an 18-month fixed-term contract has been recruited in September 2021 for a joint project of the

WATER CYCLE and BIOTECA themes of the EUR IPSL. The objective of this position is on the one hand to develop the catalog of observational data related to the water cycle theme in general and on the other hand to design and develop a database and web application to allow advanced access to observations from research projects in Siberia (Central Yakutia). For that, a GIS approach has been conducted for the management of this pilot database. The activities carried out are:

- analysis of the existing data, structuring and organization of the data;
- specification of the access and visualization portal, data output formats;
- choice of technologies, start of the development of the database and the web application.

Other activities have also been carried out with the IPSL group on land biogeochemistry: we have started to accompany the researchers of the group to help them document their data through the IPSL metacatalogue.

The geomatic engineer recruited for one year on EUR WP1 credits took charge of the installation, configuration and development of several software tools for the management of cartographic data infrastructure, applied to Earth observation data (satellite observations, in-situ measurements, data from measurement campaigns). These developments have contributed to the construction and enrichment of national data and service infrastructure, in particular in support for the management of dynamic visualization for the operational support for the measurement campaign such STRATEOLE-2 in october-december 2021.

At the national level, ESPRI continued to design and support the construction of the national GAIA-DATA infrastructure. ESPRI staff will participate in its work packages that will structure a large part of the ESPRI roadmap and development. Six working groups have been created into ESPRI for spreading workload, developing synergies and fostering commitment.

The ESPRI-IA working group (related to the IA activities) has grown in 2021 and now collaborates beyond the IPSL community and contributes to several projects.

In 2021, ESPRI significantly contributed to the European project IS-ENES3 and became the coordinator of the provision of climate data projection for the Copernicus Climate Change Service.

In 2021, ESPRI was a member of the IPSL climate services board (see below). In such a context, ESPRI will work to automate the workflow for bias correction of climate simulations and support scientific application with countries of the Global South in strong collaboration with the Institut de Recherche pour le Développement.

Communication & Mediation

Service manager

Marie Pinhas-Diena

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 also designs and organizes large-scale operations and events and produces resources for a wide and diverse audience (pupils, students, stakeholders, 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.

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 (Paris)…

Current status. 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. Three persons are currently working at ICoM: Marie Pinhas-Diena (permanent), Isabelle Genau (permanent) and Tiphaine Claveau (non permanent since 2021).

Future directions. ICoM is considering the re-organisation of the service and plans 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.

Main projects

- The launch of a new podcast “Le climat, une question de…”.
- The launch of the podcast “Chroniques du changement climatique” (a researcher of LMD-IPSL and a writer for a storytelling project with students).
- A partnership with Radio Campus Paris (season 2): introduction to broadcasting for IPSL-CGS students.
- Mozaïka: n°3: “Ocean” (2021-2030, Ocean Decade) & n°4 “Climate change and cities” (#Paname2022 to 2024).

- 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).
- Create links and collaborations with external partners, for instance the Institut de l'Océan (Sorbonne University) for the Fête de la Science or with Human Sciences Network/Labs.

Opportunities and limitations. The team lacks human resources to achieve all these projects is a major limitation.

Activities - Period from July 1, 2021 to June 30, 2022

- **The redesign of the IPSL website** www.ipsl.fr provides measurable added value from the point of view of image, referencing and interactivity. In addition, to give consistency to all our actions, website kits respecting the graphic charter of the new IPSL website are now made available to federal structures and projects.
- **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.
- **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), Les Festives (Sorbonne University).
- **Editorial and graphic support** for the publication of the 3 IPCC reports (August 2021, February and April 2022) “Détours vers le futur. L’IPSL à l’heure du GIEC”: 15 interviews of the IPCC contributors (authors) and IPSL scientifics.
- **Graphic design and animated videos** for different events and publications: The IPSL-CGS Virtual School, IPSL Presentation of activities, reports, Fête de la science, IPCC Reports, COP26…
- **Videos and podcast** “Parcours climatiques”: to promote the EUR IPSL-CGS training courses and their professional opportunities and to contribute to the constitution of the network in terms of content and resources available to students and Alumni and through contacts made (ambassadors / intermediaries); “IPSL News”: short videos to promote scientific news and/or events.
- **Mozaïka**, a series of comic strips. 1 comic strips = 1 theme, 1 box = 1 specific approach of the theme, 1 box = 1 article or 1 podcast; 2 topics: “Extreme events” (6 news + 6 podcasts “7 Extrêmes”); “Rio Summit, 30 years later” (10 news + 6 podcasts).
- **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.

On line News "Détours vers le futur. L'IPSL à l'heure du GIEC". A series of news about climate systems, knowledge and uncertainties in the face of climate change, and observation/modeling methods through interviews with IPSL climate researchers. For the approval session of the Working Group I contribution to the IPCC 6th Assessment Report (2021).
https://www.ipsl.fr/decouvrir/explorer/detour-vers-le-futur-lipsl-a-lheure-du-giec-2021/

Podcast "Parcours climatiques". Students or former students of the EUR IPSL-CGS talk about their academic career, the specificity of their master's degree, their successes and failures, the contributions of the courses they received, their future plans... This podcast presents the diversity of the courses and the professional opportunities offered by the IPSL-CGS.
https://open.spotify.com/show/3WevqVryd5ghcYou5VKPRx

Mozaïka "Vous avez dit extremes ?". In recent years, extreme events have become more and more present in our daily lives because of their frequency and intensity.
https://www.ipsl.fr/decouvrir/mozaika/vous-avez-dit-extremes/

IPSL Climate services

Leaders

Robert Vautard (IPSL) • Aglaé Jézéquel (LMD-IPSL) • Guillaume Levavasseur (IPSL) • Nathalie de Noblet (LSCE-IPSL) • Jérôme Servonnat (LSCE-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.

IPSL climate services include several activities:

- production of climate data (ESPRI), and derived data to be ready for use (bias correction, specific indices, interpolated data…), especially within the Copernicus Climate Change Service framework (C3S);
- projects with public or private partners in order to co-design solutions or data, indices to help understand the impact of climate change on the partner’s activities;
- participation to discussions and provision of expertise.

The strategy of IPSL in terms of development and partnership follows 4 main areas where IPSL expertise is strong:
develop and maintain the core Earth System Grid Federation international activity of climate projection distribution, and provide C3S with quality controlled global and regional climate projections,

- developing datasets and methods ready to use for developing countries, especially through the network developed by the IRD (Institut de Recherche pour le Développement),
- developing climate information for regional stakeholders and authorities, especially through the contacts with the Paris City and the Île-de-France Region,
- developing innovative data and projects for a few sectors, eg. the energy sector, insurance, water, and agriculture,
- developing climate information and methods around climate extremes, in particular extreme events attribution, which is designed for a large public, stakeholders and media.

Structure of the community. The activity is currently concerning several IPSL laboratories (LSCE, LMD, IPSL itself) and potentially concerning others (eg. LOCEAN, LATMOS…). In particular, the "GREC francilien" activities (science-society exchange platform with regional authorities) has built upon the expertise of several IPSL labs. Currently the activity is led by 5 scientists, but involves about 20 scientists (engineers and researchers) within IPSL.

Major tools and projects. Climate services build upon the ESGF data distribution and the ESPRI services, and IPSL is a contractor of the C3S for the 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. 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.

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 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 science-society activity; ethics considerations must be clearly discussed and stated, in particular for private partners and funding; the activity lacks mid-career managers, and often relies on senior scientists leading the activity as a side activity, and developments being made by young, fix-term contracts.

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. Thanks to the recruitment of a permanent engineer for developing data and methods for developing countries, this activity is currently being developed, through a first major dataset of processed climate projections for Africa. We are also currently discussing with several insurance companies especially on extreme events. Many activities are supported by the strong expertise in statistical methods. IPSL will finally further strengthen the extreme event attribution with a stronger participation in the WWA network and participate regularly to near-real time attribution of extremes.

Activities - Period from July 1, 2021 to June 30, 2022

In 2021-2022, IPSL has developed several actions:

- Climate projection distribution service: IPSL became in 2022 the main contractor of ECMWF for the delivery of climate projections to be inserted in the Climate Data Store of the Copernicus Climate Change Service. This is a major endeavor and stake for IPSL as it roots this core operational activity for research applications and climate services within IPSL.
- "GREC francilien" group: The IPSL and the Institut de la Transition Environnementale have joined forces to lead a systemic climate-biodiversity approach of information provision to local and regional authorities within the Île-de-France Region. This regional group, which started in 2021, also belongs to a network of similar regional groups, some with more advanced results. In 2021, and continuing in 2022, the GREC

francilien has developed a set of regional fact sheets on regional climate and biodiversity issues (https://grec-idf.eu) (only the first two fact sheets are availabel but about five more are being currently written. The group is currently advising the regional president on basic principles for the regional plan on land use management and is also advising the City of Paris on a different, specific set of actions and the climate plan.

- Climate services for developing countries: The activity started in 2022 and a first goal is to develop a set of well calibrated, easy to use, set of climate projections for Africa in order to serve adaptation for African stakeholders, with the network developed at the IRD. IPSL has hired a research engineer in order to develop this database. Once developed the plan will be to develop a set of specific indices, based on discussion with stakeholders (in particular for the agriculture and health sectors).
- Climate services projects for energy mix scenarios: In 2021 and 2022 the activity to produce datasets and develop new methods and indices to analyse risks for the electrical network has continued. IPSL strengthened its partner with the electricity transmission operator (RTE-France), in order to design a new ensemble of climate projections to be used for future energy mix scenarios assessment (typically for 2050). In parallel, the analysis of future climate-related risks for the energy production activity of another producer (ENGIE) was continued.
- Hydrology: The development of ORCHIDEE for operational use was continued, with an evaluation of the model's skill in simulating river discharge, in order to have a more operational version of the model than currently. The participation to the national program on future projections of river discharge in France (EXPLORE2). An expertise project designed to advise a company producing drinkable water on future climate risks for the water production was conducted.

Research program

IPSL has a double mandate to develop collaborative science from the existing teams in the Greater Paris area and to train students in the physical climate and climate change fields. Research activities, developed in each IPSL laboratory, are largely funded by national and internal projects, independently of IPSL coordination. IPSL, however, provides a framework where a large spectrum of expertises can be found. It has developed over the year's specific skills in several areas which are reflected in eight research themes, cited below. The research program, which benefits from a ~700 k€ / 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.

Annex details all activities and results of the thematic research program. Here we only summarize the main features of each program theme. Annex I not only describes the strategic aims in each topic but also detailed results obtained. The research program also benefits from open internal calls (~140 k€ every other year) for small innovative projects, support to invited scientists (~30 k€ / year) and support to workshops and conferences (~20 k€ / Year).

Summary of thematic research activities

Understanding past climate evolution, variability and its impact on the environment. The IPSL "Paleoclimate" theme investigates the evolution of the Earth's climate, as well as the related mechanisms and environmental responses over geological time, using observations combined with modeling experiments, in order to better understand the natural climatic variability. The theme studies various climatic contexts (*e.g.* warm and cold climates, stable climates, progressive transitions, abrupt events) in time periods ranging from the Earth's geologic past (million-year to (sub)orbital time scales) to recent (millennial to decadal variability). More precisely, the group has two major 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.

Internal and forced variability. The IPSL "variability" group aims at understanding drivers of climate variability with a triple focus: (i) Tropical climate variability (monsoons, role of external forcings, focus on the tropical Atlantic/western Africa), (ii) Polar climate variability (extreme events, climate change and impacts for indigenous communities) and (iii) Extreme or singular weather events with large-scale impacts, for instance volcanic eruptions, forest/bush fires, Medicanes and tropical cyclones, winter cold spells or climate, especially during COVID-19 outbreak. The group and its results largely benefit from the global, regional and statistical modeling expertise present at IPSL. The research also uses the simulations from the successive climate model intercomparison projects.

Water cycle. The IPSL Water Cycle theme aims to advance the understanding of the processes governing the water cycle within the atmospheric, continental, oceanic and cryospheric reservoirs. IPSL has a broad range of expertises in those topics. The aim of this theme is to strengthen the exchanges and collaborations between these topics and to develop an

integrated perspective of the water cycle. It has five main focus: (i) the Arctic regions, (ii) the changes in the continental water cycle, (iii) the tropical atmosphere, (iv) the extremes, (v) the coupling of water reservoirs in the Antarctic region.

Biogeochemistry, ecosystem and agriculture. The aim of the theme is to foster collaborative research on terrestrial biogeochemical cycles, terrestrial ecosystems and agriculture, to promote networking and collaborative actions on these topics within IPSL (5 laboratories involved corresponding to ca. 50 associate researchers and researchers), and to develop dedicated activities for students. Promoting a wide multidisciplinarity, the theme encompasses numerous scientific communities including, as an example, soil science as well as global land surface modeling. The theme focuses on the C and N biogeochemical cycles, and focuses currently on a unifying collaborative experiment designed to simulate the impacts of extreme climate conditions on plant-soil systems and biogeochemical cycles.

Marine Ecology, biogeochemistry and resources. The theme develops research into the multiple interactions between marine biota and the climate system, and focuses on four main objectives: (1) the reduction of uncertainties of carbon export estimates to meso-pelagic and deep ocean, (2) the evaluation of the role of acclimation/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 (v) scientific support to conservation. It benefits from an interdisciplinary pool of expertise, models and field campaigns developed by IPSL.

Atmospheric composition and air quality (COMPOSAIR). The "Atmospheric composition and air quality" IPSL group focuses on describing and understanding the formation and evolution of chemical compounds in the atmosphere from the boundary layer (air quality) to the stratosphere, in particular the life cycle of chemical compounds that impact health, ecosystems and the climate, such as ozone, aerosols, but also precursor compounds such as nitrogen oxides or volatile organic compounds. These compounds are reactive and their transformations (photochemistry, aqueous chemistry, formation of secondary aerosols, etc.) are strongly influenced by environmental conditions. In situ observation, remote sensing and modelling approaches are used. Areas of study range from the street scale to the continental scale. The group also strengthens and develops the links between research and teaching by contributing to training programs for M1, M2, and engineering school students as well as by supervising PhD students. In 2022, intense preparation and coordination of several field campaigns took place in the Paris area.

Solar systems. The exploration of the Solar system and discovery of exoplanets now allow for comparative studies of Earth and its various extra-terrestrial analogues. The IPSL “Solar systems” group is involved in these studies through its broad expertise, which incidentally allows for testing its Earth models in extreme conditions. It benefits from modelling tools used to interpret the observational data gathered in the solar system, complemented by astronomical observations. These tools include climate models, closely related to the IPSL Earth GCM, as well as laboratory simulations aimed at reproducing the exotic conditions in the solar system and in exoplanets.

Statistics for Analysis, Modelling and Assimilation. The “SAMA” group 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 modelling 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.

Thematic activities and in 2021-2022 have allowed the funding of 28 traineeships, 2 post-doctoral scientists and 4 research engineers to support research activities.

Training and education program

The very rapid evolution of climate and environmental transitions gives a rapidly growing importance to the different aspects of training. The "École Universitaire de Recherche" (EUR), called "IPSL Climate Graduate School" has a training committee in charge of these issues. It is made up of about ten people, representing the different laboratories of the IPSL. Almost all of them are research professors, with the capital exception of Estelle Fournel who is in charge of the program in its various dimensions.

The committee meets about 5 times a year. It functions in two main ways, both of which contribute to the 6 or 7 actions that determine its role since the beginning of the EUR. On the one hand, it evaluates requests "as they come in" (20 projects in the framework of its 2020-2021 call for proposals). It also develops more permanent actions, which are developed below. The actions set up since the beginning of the project have all been continued and have all been the subject of targeted meetings throughout the year.

They are as follows.

Action 1. Coordination / federation of Masters

At the Master 1 level, the implementation of a common knowledge base in climate sciences is now becoming very concrete, in the form of 7 teaching units at the S1M1 level of 3 ECTS each, in digital resources, which are currently being developed.

At the Master 2 level, the implementation of a similar action has been impossible for the moment in the complex framework of the Ile de France region. It is more from the point of view of tools that the IPSL has been able to play an important role. A training section has been entirely rewritten, redesigned and developed during the creation of the new IPSL website: https://www.ipsl.fr/formation (https://www.ipsl.fr/en/education/). All EUR IPSL-CGS training courses as well as a selection of projects and pedagogical innovations are presented and referenced there.

The role of IPSL-CGS has also been important in setting up various field campaigns for students.

Action 2. International

The 3rd IPSL Virtual School for international students, at the bachelor and master level (M1, M2) has taken place in May 16-18, 2022. This time, the theme is data and Artificial Intelligence.

Support to other summer schools has also been provided, as well as support to the "Office for Climate Eductation", which has the main goal to provide secondary school teachers worldwide with pedagogical material which can range from IPCC reports based material to material from European research projects.

Action 3. P2 "Pre-doc" program

IPSL-CGS introduced a pre-doctoral program offering, for students graduating from M2 and accepted in PhD, an additional preparatory period of 3 months to be placed between October and December before the start of their PhD. The objective of this preliminary period is to allow future doctoral students to prepare their PhD in the best conditions. As soon as they are selected for the program (at the end of the doctoral school competitions), students joining the "Pre-doc" curriculum, with the help of a tutor who is their manager, a personalized program allowing them to strengthen their initial training, using for example the course offered by the M2 or by the doctoral school (not exhaustive, non-exclusive), etc. The graduate program "Pre-doc" and the activities carried out by the student will be mentioned in the thesis diploma supplement.

Action 4. Support to doctoral schools (PhD funding)

Support was provided to the partner universities for 4 PhD grants.

Action 5. Renewal of teaching methods

Since 2019, numerous other projects of innovative and practical learning were supported through the education call for proposal of IPSL. For example:

- A project of numerical teaching units for Master 1, which will contribute to build a consistent education chain from fundamentals of the climate system to impacts and solutions. This work is carried out in a concern of pedagogical alignment (coherence between the targeted learning outcomes, their evaluation and the learning devices).
- The development and maintenance of SIMCLIMAT educational software and smartphone application (users: from high school to undergraduate students and societal relays) which can be used to introduce processes controlling climate. This software can be used to discuss past climate variations and the different natural factors that influence climate (astronomic forcing, natural perturbations in the carbon cycle). The effect of climatic feedbacks can be shown by plugging or unplugging feedbacks. It also can be used to discuss global warming, and test different carbon dioxyde emmissions scenarii.
- The e-CaIPSuL project, consisting of short undergraduate videos on targeted climate-related topics. All 43 educational videos from the project (French and English versions) are online and referenced on the IPSL-CGS's CanalU channel (https://www.canal-u.tv/producteurs/ipsl), with also educational spin-offs for other educational actors (Éditions Nathan, ILC of the Ontario Office of Educational Telecommunications...). They were also used in the framework of other training courses such as, for example, the Climate-KIC Journey School planned for the summer of 2020. The French and English illustrations used in these videos are available to the IPSL's teacher-researchers for possible reuse in other teaching contexts (e.g. course support).
- The Master's degree in climate and media entirely delivered on-line (Université Paris-Saclay and ESJ de Lille).
- Development of a teaching unit in problem-based learning with the École Normale Supérieure and Paris-Saclay in M1 on ocean atmosphere dynamics (3 ECTS).

Action 6. Tutoring and Alumni

The definition of a mentoring and alumni policy has been a major focus of work, particularly at the SU level, but with mixed results.

Halfway through the existence of the EUR program, it can be said that it is globally a success. However:

- Some elements have come up against the complexity of the Île-de-France landscape. Its rapid evolution has greatly complicated several projects, in particular the work on the various master's programs for the use of students.
- It remains difficult to define an "IPSL" identity on social networks. Solutions can be envisaged in the form of specific days.
- New opportunities may also arise: for example, making the IPSL one of the "pilot" sites for training in climate issues that affects all citizens.

Several other training actions took place. The new SIRTA observatory hosted the IPSL Climate and Environment Experimental training school in April 2022 (conducted annually since 2016). Twenty-four third-year bachelor (L3) students from different Paris-region universities benefited from a one-week intensive training on climate, air pollution, and renewable energies. The students participated in experimental work and data analyses.

SWOT analysis

04

Strengths

IPSL provides a framework to support bottom-up initiatives in a relatively informal way. It legitimates and facilitates spontaneous collaborations, projects across the different research units. It has allowed the community construction of large-scale projects and programs. IPSL is invoked whenever an idea, a project, a discussion, reaches the community scale. As such, IPSL is a robust object in the landscape of climate research in France and it is designed for scientific needs.

IPSL gathers a large pool of expertise in several fields. It has a critical mass in most areas of physical climate processes, climate modelling, observation strategy, data management. Whenever a science question is on the table, raised by external players, it is usually easy to identify a group of experts with the appropriate knowledge to tackle the question.

IPSL leads structuring research tools (observation, models) and has leadership or strong position in the European landscape in several fields and infrastructures.

IPSL leads a large research-training program (EUR IPSL-CGS) fostering a number of transversal activities across research units. This program is key to IPSL dynamics.

IPSL scientific credit allows informal, yet internationally-recognized, structures to be established and maintained over time (e.g ESPRI data center, CMC modeling center, SIRTA observatory…).

Weaknesses

Weak status of the IPSL institution: despite the visibility (national and international) and attractivity, its status ("federation de recherche") is weak, not well suited to conduct its specific missions. IPSL is a unique structure in the research landscape, with major responsibilities of animation and coordination but weak ties to sponsor organisations. Its missions also include specific developments such as science-society programs or operational activities (data/computing service, monitoring, climate services, mediation, …), requiring flexibility in a fast moving environment (changes in needs, in skills required), and priority in non-mainstream activities which can hardly be offered by the current research system.

Difficulty to fund and hire specific science-society staff profiles, with multidisciplinary skills ranging from mathematics and engineering to project managers, communication and mediation, as needed for a successful translation of information to a range of stakeholders to make a successful co-construction of knowledge to approach climate change issues.

Interdisciplinarity: IPSL already brings together a large spectrum of disciplines, which allows the achievement of large community-size projects, but IPSL keeps its expertise mostly in physical science. Interdisciplinary projects are achieved essentially through partnerships. While this is not a major barrier, IPSL would yet benefit from a specific way to organise interdisciplinarity to tackle environmental problems in order to have a holistic/systemic approach.

Insufficient integration and interactions between modelling and observational activities. This prevents it from leveraging all the IPSL potential in observational studies for the development, evaluation and improvement of its global and regional climate models; It also prevents efficient combined use of model output and observations to perform advanced process studies.

Weak interactions between different regional and global modelling efforts: The IPSL effort on climate modelling remains focused on assembling the different model components at global scale

with weak interactions with efforts in regional climate simulations. A common strategy has been built but there is a lack of resources to lead a real transformation effort.

A multi-site organisation (with > 1-hour travel across sites) which represents a challenge to achieve a shared culture and a seamless communication.

Opportunities

Starting major national projects such as GAIA DATA, and submitted programs if funded, such as the PEPR TRACCS on climate model development and climate services (if funded), new program GAIA DATA. The EUR program can also be an opportunity to have longer-term or permanent staff on dedicated actions and topics.

Increasing needs for society needs for climate information, energy and ecology transition in an organised and multidisciplinary way to which IPSL is well positioned to contribute; in particular, IPSL can be a major international provider in the provision of well organised climate projections and monitoring data.

The need for holistic or systemic approaches to deal with climate adaptation and mitigation, is an opportunity for IPSL to launch and lead new interdisciplinary initiatives and new partnerships.

Threats

Lack of attractivity and issues of staff retention in several fields (system admin, DevOps, data science, HPC), inability to hire due inter alia to low salaries, slow process, and regulatory issues.

Loss of critical mass in communication/mediation due to the current scattering of resources and the difficulty, given existing tensions on positions, to prioritise institutional requests for permanent positions on these activities.

Lack of HPC experts and inability to attract new staff to restructure and adapt existing model codes to new HPC architectures. This poses a risk on our ability to run large model code on exascale supercomputers that are expected to rely heavily on GPUs. Both restructuring and porting of large amount of codes are required.

Loss of interest in the more fundamental aspects of our sciences: young scientists are now fully aware of climate and environmental issues and may seek projects and careers in solutions development with a consequence that basic developments in model, instrument, or algorithm are perceived as being of lower priority by young scientists and funding agencies alike.

Loss of interest in IPSL from the research community given the ongoing raising role of subregional Universities, which could mask the added value of IPSL, especially if the sponsor universities do not clearly support the role of IPSL at a high level.

Research activities and results

Annex

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

Theme leaders

Aline Govin (LSCE-IPSL) • Charlotte Skonieczny (GEOPS-IPSL)

The IPSL "Paleoclimate" theme investigates the evolution of the Earth's climate, as well as the related mechanisms and environmental responses over geological time, in order to better understand the natural climatic variability. We study various climatic contexts (e.g. warm and cold climates, stable climates, progressive transitions, abrupt events) in time periods ranging from the Earth's geologic past (million-year to (sub)orbital time scales) to recent (millennial to decadal variability). Complementary expertise allows the different components of the climate system (such as the ocean, atmosphere, ice sheets, vegetation, dust) to be investigated. We have, within the theme, exceptional tools at our disposal:

Very diverse state-of-the-art analytical facilities for the dating and reconstruction of multiple climate variables using various types of archives (e.g. marine and terrestrial sediment cores, ice cores, corals, trees), with a special emphasis on the calibration of paleo-tracers under modern conditions;

- 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, as well as the direct simulation of tracers (e.g. geochemical and isotopic tracers, bio-indicators).

Most of our analytical facilities belong to analytical platforms (e.g. PANOPLY, ALYSES, GEORG, CISE) 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 paleoclimatology, in a quasi-unique manner at the national and international level.

This research theme involves around 35 active scientists from five IPSL research institutes (GEOPS, LMD, LOCEAN, LSCE, METIS), while about 100 IPSL scientists subscribed to the theme's internal mailing list. The group is currently leader of and involved in several international and European projects (e.g. Belmont Forum, European Research Council). It also leads numerous national scientific projects (e.g. French National Research Agency, French program "Les Enveloppes Fluides et l'Environnement"), in collaboration with the French paleoclimate community outside the Paris region. Thus, the whole IPSL paleoclimate group has strong national and international collaborations. IPSL paleo-scientists 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). International exchange and cooperation programs are also developed on specific topics. Partnerships with the South are particularly active through the French National Research Institute for Sustainable Development and its abroad international laboratories. 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). 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 ongoing writing of a white paper on paleoclimate studies in France (to which the IPSL paleoclimate community strongly contributes) will hopefully provide new funding and hiring opportunities in the future.

Current activities of the “Paleoclimate” group have two major 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. Five objectives have been specifically defined:
Develop fully federative research scientific projects within the theme. Two federative topics have been identified: “Teleconnections around the Southern Ocean”, and “Teleconnections across monsoonal systems”;

1. Upgrade the rapid and simple Analyseries software, internationally run with success for 30 years and now obsolete;
2. Develop a simple and adaptive tool to easily and quickly compare paleoclimate data to paleoclimate model outputs;
3. In collaboration with the IPSL Center for Earth Observations and ESPRI: Develop databases for the perennial archiving of paleo-data using international standardized formats;
4. In collaboration with other IPSL themes and the IPSL Climate Modeling Center: perennially include water stable isotopes in all components of the IPSL Earth System Model.

Activities - Period from July 1, 2021 to June 30, 2022

The main achievements of the IPSL paleoclimate group are described below for the 5 objectives listed above:

1. Federative project “Southern Ocean”: The joint supervision of IPSL-funded master internships allowed two paleoclimate fields to develop close links, leading to two very high-impact publications, one joint project submitted to the French National Research Agency, and one IPSL-funded postdoc position starting in fall 2022:
2. The upgrade of the widely used Analyseries software progresses under the format of master internships and projects for engineer schools. Two tabs (insolation, mathematics) have been converted from the original C++ code to Python;
3. A relatively simple and adaptative tool has been developed to foster and facilitate the comparison of model outputs to paleoclimate records (see Highlight below). Intensive training gathered tens of participants;
4. The international African Pollen Database (https://africanpollendatabase.ipsl.fr/#/home) has been upgraded using the international Linked PaleoData standardized format. The website includes (1) an online tool to determine pollen grain species that contains 1065 pictures, (2) a database of 744 fossil African pollen records, and (3) a database of 110 modern African pollen sites. The companion IPSL Paleo Data Base is still under development;

5. About 20 scientists from different IPSL themes defined the strategy to perennially include water stable isotopes in the IPSL model. Two 18 months-long engineer positions have been advertised for the ocean and vegetation components, respectively. One candidate has been selected for the ocean component. The other position remains open.

The paleoclimate group contributed to:

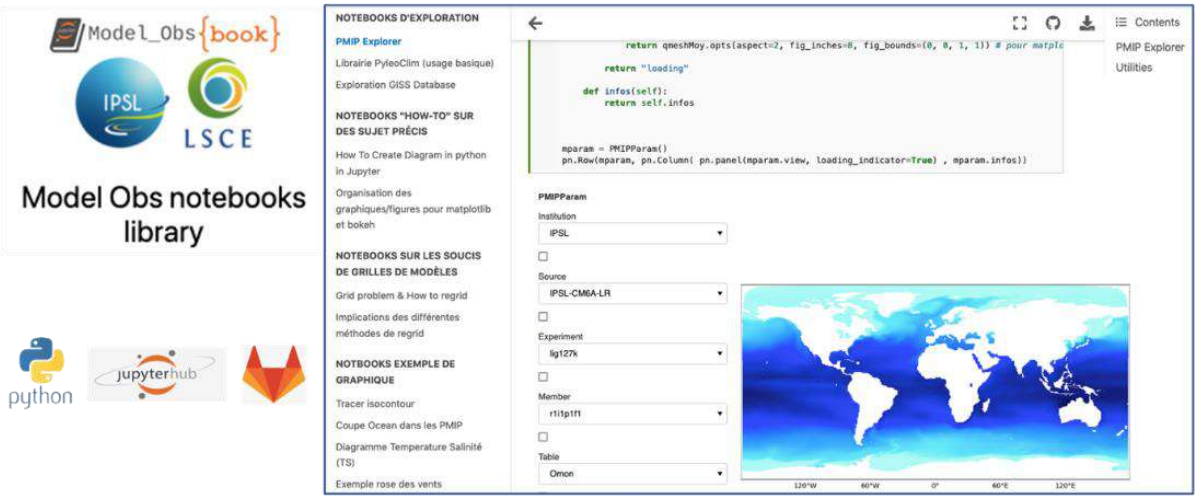
- student's training activities via three master internships, one project for engineering schools, and the participation of PhD students to JupyterLab and Python workshops. Many members of the IPSL paleoclimate theme are involved in Bachelor and Master degrees of Paris region;
- IPSL communication activities through the 30 years of the PMIP program, two online articles[11], a TV documentary (Ushuaia Nature), and 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).

Model-data comparisons are fundamental in paleoclimate studies to test hypotheses of mechanisms at play during a specific climatic event or transition. Yet, the analysis is clear: observers and modelers lack time and do not necessarily investigate new paleoclimate reconstructions or model experiments to address specific questions of colleagues. The IPSL "Paleoclimate" theme hired during one year an IT engineer (Laurent Troussellier) to design an easy-to-use and adaptive tool facilitating model-data comparisons for non-experts and to train interested IPSL scientists to the use of this tool.

The JupyterLab ecosystem is selected for its flexibility, its possibility to share notebooks, and its long-term sustainability. About 30 notebooks have been developed and provide examples of algorithms and explanations on various topics: e.g. how to use catalogs to search and select model simulations (PMIP, CMIP, DeepTime), how to plot model outputs, how to import, read and visualize data tables, how to compare model simulations and paleo-records, how to draw nice figures.

All notebooks are shared under a single website (see next page). Because learning the JupyterLab environment and Python computer language may be intimidating, training workshops gathered tens of participants from the IPSL "Paleoclimate" theme and beyond.

[11] https://www.ipsl.fr/recherche/les-thematiques-scientifiques/paleoclimats/la-paleoclimatologie-a-la-recherche-du-temps-perdu/ https://www.ipsl.fr/recherche/les-thematiques-scientifiques/paleoclimats/maximum-thermique-et-avenir-climatique/



https://ipsl.pages.in2p3.fr/projets/paleo-ipsl/modelobsnotebooks/intro.html

Illustration of the website sharing Jupyter notebooks facilitating model-data comparisons.

Over the period of interest, two publications explicitly acknowledged the IPSL funding:
Fang, S.-W., Khodri, M., Timmreck, C., Zanchettin, D., & Jungclaus, J. (2021). Disentangling internal and external contributions to Atlantic multidecadal variability over the past millennium. *Geophysical Research Letters*, 48, e2021GL095990. doi: 10.1029/2021GL095990

Yang, J. W., Brandon, M., Landais, A., Duchamp-Alphonse, S., Blunier, T., Prié, F., & Extier, T. (2022). Global biosphere primary productivity changes during the past eight glacial cycles. *Science*, 375(6585), 1145-1151. doi: 10.1126/science. abj8826.

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)

Understanding the internal and forced climate variability is a long-standing scientific question. Modes of internal climate variability can emerge from processes affecting individual components of the climate, such as the atmosphere, the ocean, the cryosphere or the land surfaces. They can also involve a coupling among them. Examples of climate variability include the Madden-Julian oscillation, intra-seasonal to interannual monsoon pulses, El Niño Southern Oscillation, the North Atlantic oscillation, the southern annular mode, the stratospheric circulation (including the Quasi-biennial oscillation), or the Atlantic and Pacific multidecadal variability. On the other hand, external forcing resulting from volcanic eruption, fires or variability in anthropogenic emissions also impact climate variability.

The topics of three main research groups working on internal and climate variability were identified:

- Tropical climate variability (monsoons, role of external forcings, focus on the tropical Atlantic/western Africa);
- Polar climate variability (extreme events, climate change and impacts for indigenous communities);
- Extreme or singular weather events with large-scale impacts, for instance volcanic eruptions, forest/bush fires, medicanes and tropical cyclones, winter cold spells or climate during COVID-19 outbreak.

Structure of the community. Four IPSL laboratories are involved: LATMOS, LSCE, LMD and LOCEAN and 51 researchers and engineers were identified in this theme with variable degrees of involvement.

Major tools and projects. This research largely relies on climate global and regional models. In particular, the IPSL climate models are widely used, including its atmospheric component LMDz and its oceanic component NEMO. The research also uses the simulations from the successive climate model intercomparison projects. The research is also closely related to observational campaigns led by team members. For example, in 2021-2022, they include the THIN ICE campaign in the Arctic and the CNES-CNRS Strateole 2 long-duration balloon campaign in the tropical upper troposphere.

Opportunities and limitations. IPSL has a world renowned reputation on the analysis of climate variability. Furthermore, IPSL is already well identified by the research community, stakeholders or media. However, activities related to the theme are various and scattered between different laboratories and research teams, with limited room for the development of further collaborations. We also identified a lack in the tools to promptly provide solid information in case of extreme events with large societal impacts.

Main orientations. In this context, the activity aims at:

1. fostering discussions and exchanges on complementary aspects of research led at IPSL on the internal and forced climate variability, including extreme events;
2. making available to the research community key diagnostics to disseminate and promote best practices on the topic of statistics and climate change and extreme events with large societal impacts;
3. promote the formation of student from the research activities related to the theme.

Activities - Period from July 1, 2021 to June 30, 2022

The research based on the large involvement of IPSL in the CMIP6 (climate modelling intercomparison project phase 6) exercise has led to several achievements. A better understanding of climate models climate sensitivity has emerged as a priority from CMIP6. Among other, the tuning of the IPSL climate model and the important research question and choised raised were documented in Mignot *et al.* (2021). Bonnet *et al.* (2021) also raised the possibility that the observed climate variability in the North Atlantic has attenuated the forced climate changes, with a potential acceleration of global warming in the coming decade.

Three Master 2 internships were funded in three different laboratories of IPSL: on the organisation of atmospheric convection, on the tropical atmospheric-oceanic coupling and Arctic depressions in the IPSL model.

We have contributed to the new IPSL web pages, with a focus on monsoon with the contribution of Juliette Mignot (LOCEAN-IPSL), and a focus on weather extremes led by Davide Faranda (LSCE-IPSL).

On January 15th, 2022, the underwater Hunga-Tonga volcano exploded in the most powerful blast since at least the eruption of Mount Pinatubo in 1991. Atmospheric waves were triggered and propagated several times around the globe, while the volcanic plume reached an altitude of 58 km, setting a new observational record. IPSL scientists are currently involved in the study of the waves and the plume of the Hunga Tonga, and its radiative impact and several studies have been submitted or are in preparation for high-impact journals (https://www.researchsquare.com/article/rs-1562573/v1).

This exceptional event received significant attention from the media with interventions from IPSL scientists
(in the general and scientific press https://tinyurl.com/mrv35wzt)

Publications explicitly acknowledging the IPSL funding:
Boucher *et al.* 2020. https://doi.org/10.1029/2019MS002010, Open access
Mignot *et al.* 2021. https://doi.org/10.1029/2020MS002340, Open access
Bonnet *et al.* 2021. https://doi.org/10.1038/s41467-021-26370-0, Open access

Water Cycle

Theme leaders

Jan Polcher (LMD-IPSL) • Ludivine Oruba (LATMOS-IPSL)

Earth has only a finite volume of water which is being recycled through the various reservoirs. This is what is called the water cycle. Only a small part of this cycle is actually fresh water and thus an essential resource for human activities. Climate change, meteorological processes as well all forms of life are strongly affected by changes in this continuous and interconnected cycle. Climatic changes in the water cycle lead to modifications of the distribution and intensity of precipitation, water mass circulations in the ocean and air movement in the atmosphere, the evolution of glaciers and ice-sheets, continental evaporation, groundwater transports and water quality. In order to maximise this resource human have managed it over the last milenia based on past climate events. A large fraction of changes in frequency and magnitude of natural disasters affecting livelihoods (eg. Floods, droughts, tropical cyclones) are directly attributable to modifications in the water cycle and perturbations to the delicate balance of processes within this cycle and the way humans manage the water. The infrastructures created were conceived for past climates and they might be ill suited for events in the future. It is thus essential for research to examine not the natural continental water cycle but the one which is under human control.

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 exchanges and collaborations between these disciplines and thus develop an integrated perspective of the water cycle.

Five multidisciplinary topics have been selection in order to achieve this integrated vision of the hydrological cycle:

- evolution of the water cycle in the Arctic region;
- climate and anthropogenic driven changes in the continental water cycle;
- organization of the tropical atmosphere by ocean and land;
- extremes in the water cycle: precipitation and droughts;
- the coupling of the water reservoirs of the Antarctic region.

Structure of the research community. The laboratories involved are the LMD (Laboratoire de Météorologie Dynamique), LATMOS (Laboratoire ATmosphères, Observations Spatiales), LSCE (Laboratoire des Sciences du Climat et de l'Environnement), GEOPS (Géosciences Paris-Saclay), METIS (Milieux Environnementaux, Transferts et Interactions dans les hydrosystèmes et les Sols) and LOCEAN (Laboratoire d'Océanographie et du Climat).

IPSL 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; some are based on observations (satellite or in situ) when others use numerical models or conduct experimental catchment studies.

Major tools and projects. AWACA (Atmospheric Water Cycle over Antarctica: past, present and future): This Synergy ERC contributes directly to the Antarctic topic of the theme and will help further our understanding of the processes within the water cycle of the region.

Opportunities and limitations. The Arctic branch of the theme has suffered from the recent loss of our colleague Christophe Grenier, a recognized researcher in their field who was the driving figure behind one of the topics of the theme. The international context also led to the cessation of academic collaborations with Russia and thus the experimental sites in Siberia cannot be maintained anymore and the data continuity is lost. The future of this topic will be discussed in forthcoming meetings.

Activities - Period from July 1, 2021 to June 30, 2022

This section is focused on the past year (if major results arrive in May, there will be a possibility to revise, but we need to complete this section by 22 April):

- Virtual meeting, held on July 6th 2021, for the whole "Water Cycle" theme to discuss further, and together, the next steps
- In 2021, an action has been undertaken to bridge methodologies used in hydrology and climate sciences. An engineer has been hired for 12 months (Vincent Payer, start: Sept 1st 2021) with the aim to build tools which allows to transfer data from the Geographical Information System (GIS) used extensively by the hydrologists to and from the gridded data formats used by climate scientists. This should lead to a full interoperability between both approaches to handling geographical data. As this development is also relevant to the theme BioTECA (theme 4 of EUR-IPSL), they will contribute to the budget through a 6-month extension of the contract. The engineer is supervised by GEOPS and LSCE, will tackle the objectives of the work through data sets collected in Arctic (Iakouty/Siberia, link with topic #1) with a strong contribution from ESPRI Data Center.
- The theme supports 3 master thesis internships in 2022.

Communication. IPSL news (04/10/2021), "A l'avant-poste du changement climatique, la Sibérie dégèle" (A. Séjourné, GEOPS; C. Grenier, LSCE): associated to topic 1 (Arctic) and partly supported by 2 M2 internships.

Land biogeochemistry, Ecosystems and Agriculture (BIOTECA)

Theme leaders

Nicolas Vuichard (LSCE-IPSL) • Frédéric Delarue (METIS-IPSL)

Terrestrial ecosystems play an important role in global biogeochemical cycles, notably the carbon and nitrogen cycles. Tightly associated, these biogeochemical cycles are strongly altered by agricultural practices and the ongoing climate change. Understanding the role of these biogeochemical cycles and their interactions are essential for answering key questions concerning the future trajectories of anthropogenic and natural ecosystems. The theme "Land biogeochemistry, ecosystems and agriculture" (BIOTECA) aims to study the direct and indirect impact of anthropic activities on the C and N biogeochemical cycles in terrestrial ecosystems (anthropogenic and natural ecosystems). BIOTECA therefore covers research focusing on the C and N biogeochemical processes occurring at various spatial scales (molecular, watershed and global scales) and temporal scales (from the beginning of the industrial age until the next decades). In such a view, BIOTECA promotes actions aiming to bridge the spatial and temporal gaps between (i) micro- to macroscales and (ii) past and future trajectories.

Structure of the research community. The aim of the BIOTECA theme is to foster research activities on terrestrial biogeochemical cycles, terrestrial ecosystems and agriculture, to promote networking and collaborative actions on these topics within IPSL (5 laboratories involved corresponding to ca. 50 associate researchers and researchers), and to develop dedicated activities for students.

Major tools and projects. Promoting a wide multidisciplinarity, BIOTECA encompasses numerous scientific communities including, as an example, soil science as well as global land surface modelling. Among structuring projects of these scientific communities, it is worthy to note the recent funding of 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 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. Limitations in the theme are directly linked to (i) the numerous scientific communities represented within and to (ii) the existence of a new highly-funded program (e.g FairCarboN has a funding of ca. 40 M€ for the next 6 years, a period for which BIOTECA has a funding of 300 k€). After identifications of these limitations, BIOTECA has re-oriented its actions as an incubator of ideas favoring the emergence of new concepts and innovative approaches on two structuring axes:

1. from micro-to macro scale climatic conditions in land ecosystems and agriculture;

2. The Global Land Surface Model: ORCHIDEE. (ORganizing Carbon and Hydrology In Dynamic Ecosystems Environment).

Activities - Period from July 1, 2021 to June 30, 2022

Several significant activities were identified for the period from July 1, 2021 to June 30, 2022:

1. 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 for public access to data. This metadata catalog benefits from the support of ESPRI-OBS, an infrastructure developed at IPSL. In association with the theme on Water cycle, a research engineer was recruited for 18 months to develop this metadata catalog. Thanks to this initiative, a first dataset has been published on Carbonyl sulfide flux measurements collected near Paris over a 7-year period (https://doi.org/10.14768/6800b065-dcec-4006-ada5-b5f62a4bb832, Belviso *et al.* 2020);
2. BIOTECA also lays the groundwork for an ambitious and unifying experiment. Aiming to simulate extreme events (successions of drought and rain cycles) on plant-soil systems and to investigate their effects on soil C and N cycle, this experiment will bring together geophysics, biology, geochemistry and modeling. This experience will benefit from the CNRS Ecotrons infrastructure managed by Samuel Abiven (École Normale Supérieure). More specifically, experiments will be performed in Ecolab systems allowing accurate real-time programming of weather conditions (temperature, humidity and precipitation). Several BIOTECA meetings were then organised to design this experience planned for October 2022;
3. dating of dissolved organic carbon in thermokarst lakes. As thermokarst lakes play an important role for climate change feedbacks, these radiocarbon dating will be helpful to assess whether potential CO_2 emissions are directly related to the mobilization of old carbon pools that were, until now, trapped within the permafrost;
4. Five master 2 internships were funded by BIOTECA.

One publication funded by IPSL through BIOTECA was recorded:
Le Gaudu *et al.* (2022; https://doi.org/10.1016/j.scitotenv.2022.153601)

One dataset funded by IPSL through BIOTECA was recorded: Carbonyl sulfide mixing ratios, flux measurements and vertical distribution (https://doi.org/10.14768/6800b065-dcec-4006-ada5-b5f62a4bb832)

Global carbon budget: what are the impacts of forest fires?

Recently identified post-fire carbon fluxes indicate that, to understand whether global fires represent a net carbon source or sink, one must consider both terrestrial carbon retention through pyrogenic carbon production and carbon losses via multiple pathways. Here these legacy source and sink pathways are quantified using a CMIP6 land surface model to estimate Earth's fire carbon budget.

Over the period 1901–2010, global pyrogenic carbon has driven an annual soil carbon accumulation of 337 TgC yr−1, offset by legacy carbon losses totalling −248 TgC yr−1. The residual of these values constrains the maximum annual pyrogenic carbon mineralization to 89 TgC yr−1 and the pyrogenic carbon mean residence time to 5,387 years, assuming a steady state. The residual is negative over forests and positive over grassland-savannahs (implying a potential sink), suggesting contrasting roles of vegetation in the fire carbon cycle. The paucity of observational constraints for representing pyrogenic carbon mineralization means that, without assuming a steady state, we are unable to determine the sign of the overall fire carbon balance.

Constraining pyrogenic carbon mineralization rates, particularly over grassland-savannahs, is a critical research frontier that would enable a fuller understanding of fire's role in the Earth system and inform attendant land use and conservation policy.

Bowring, S.P.K., Jones, M.W., Ciais, P., Guenet B. and Abiven S., Pyrogenic carbon decomposition critical to resolving fire's role in the Earth system. *Nat. Geosci.* 15, 135–142 (2022).

Marine biogeochemistry, ecology, and resources

Theme leaders

Marion Gehlen (LSCE-IPSL) • Francesco d'Ovidio (LOCEAN-IPSL)

The future decade will be crucial for greenhouse gas emissions, calling for a clear understanding of associated biogeochemical cycles and their interaction with climate change, land and ocean surfaces, agriculture and ecosystems. These must now be studied together. Important questions are on the table such as the carbon cycle and biogeochemical fluxes in the mesopelagic and deep ocean, or at the ocean interfaces, the trophic chain functioning and the impact of climate change.

Marine organisms are an integral part of the climate system. They drive biogeochemical cycles of major elements (e.g. C, N, P, Si) as well as associated trace elements (e.g. Fe, Co, Mn). They contribute to the partitioning of C between the atmosphere and the ocean on glacial-interglacial time scales. At the same time, the physiology, morphology, genomes, distribution, and community structure of marine populations have been evolving in close connection with past climate variability. Therefore, the relation between marine biota and the climate system is a central question also in marine biology, and a pressing one for predicting the evolution of ecosystem services in terms of food security, health, economy, and biodiversity. Including marine organisms in climate models means to couple processes occurring at the cellular level with Earth system dynamics. This exercise involves fundamentally heterogeneous processes, and spans a wide range of spatio-temporal scales. It is a balancing act, which consists in choosing a level of biophysical detail, which is complex enough to be representative, but simple enough to be treated and parameterized. How to deal with this unavoidable necessity for approximation is currently a great challenge. Addressing it requires to reduce the gap between climatic spatiotemporal scales and biological scales as well as to include more biological traits.

At IPSL research into the multiple interactions between marine biota and the climate system is developed along four main objectives:

1. the reduction of uncertainties of carbon export estimates to meso-pelagic and deep ocean,
2. the evaluation of the role of acclimation/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 (v) scientific support to conservation.

Structure of the research community. Laboratories involved: LSCE, LOCEAN, LMD, METIS, about 50-100 people involved.

Major tools and projects. 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.

The contribution of IPSL scientists to IPCC and the need to model the Earth system remains a strong structuring force for integrating together physics 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 within IPSL provides direct access to top level national and international biological collaborations.

The Museum provides also a privileged channel for reaching policy makers and linking our research activity to conservation. In terms of national position, together with the IPSL modelling facilities and capabilities, a great advantage for the French biophysical 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 a group of specialists in ocean tracer's analysis and modeling both equipped with cutting edge tools (analyticals or models) as well as paleo- oceanographers using proxies developed based on the knowledge of ocean tracers.

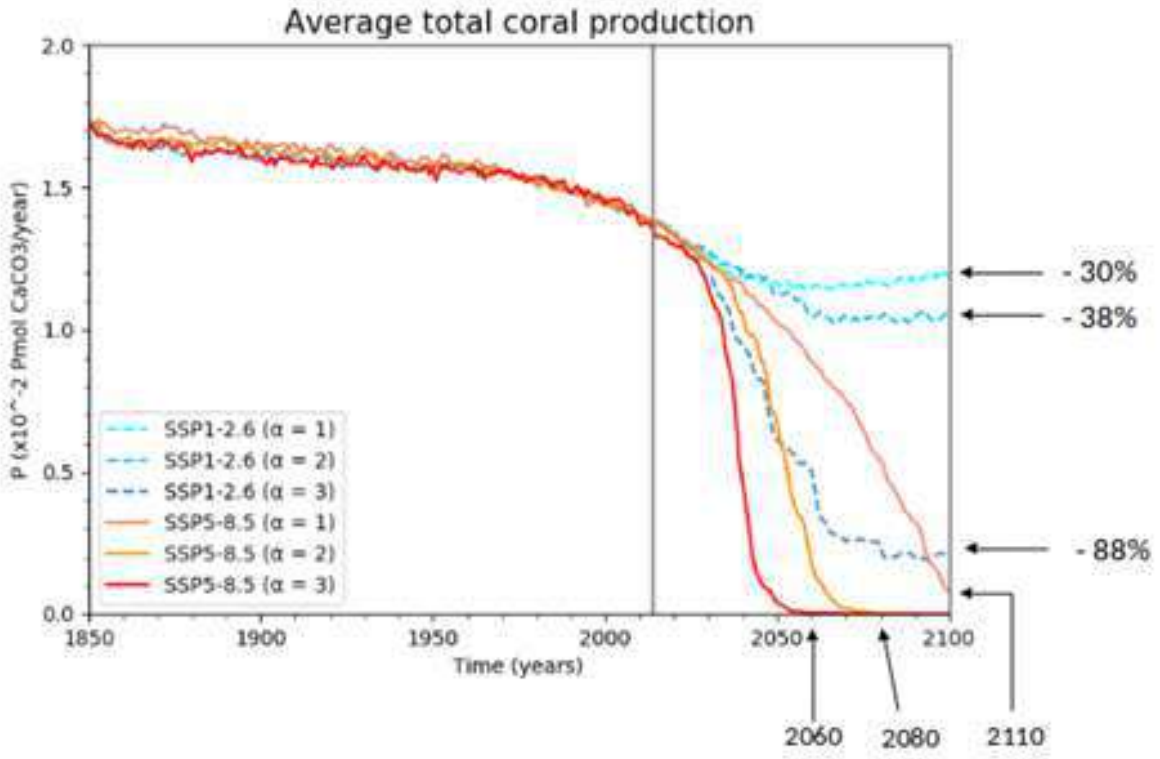
Major advances in the field. The main contributions of our community are in terms of the Coupled Model Intercomparison Project (CMIP6) ICPP reports, and focus on models and process studies of climate-phytoplankton feedbacks with special emphasis on the carbon cycle. Emerging actions point towards the 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 conservation, with for instance a contribution to the scientific basis for the establishment of the Marine Protected Area of St Paul and Amsterdam.

Opportunities and limitations. The advantage and limitation of the Theme is its great diversity, solid structure, and great scientific productivity, highlighted by roles in ICPP activities. We believe that the Theme has no vocation to alter the IPSL IPCC dynamics that is already very effective. Our work therefore aimed at breaking the interlab barriers on other sub-themes in order to activate a multilab (i.e., IPSL) potential elsewhere.

Activities - Period from July 1, 2021 to June 30, 2022

Two different strategies have been deployed. In 2020, we supported some small incitative actions, in the form of Master 2 grants aimed at exploring new research directions. Some papers are now in preparation. In 2021 we aimed at injecting some major novelty in our community, and requested funding for opening a call for a two-year invited researcher grant. Four high level projects have been received, and a selection committee finally chose the project of J. Caccavo, who has started only this month (April 2022). This project focuses on "Climate genomics", that is, on the link between genomics and climate sciences, considering the case study of a fishery threatened by climate change in the Southern Ocean.

Papers from the Master projects financed by the thème in 2020 are in preparation. Note that the support for 2021 has been invested into a 2-year postdoctoral position that has just started. A preliminary result of a paper from a Master 2 result and in preparation is in the figure below.



Evolution of coral production (carbonates) as a function of SSP scenarios and of different climatic sensibility. Red/orange: SSP5-8.5 (loss), blue SSP1-2.6 (reduction). Paper in preparation (Result from a Master 2 internship).

Atmospheric composition and air quality (Composair)

Theme leaders

Juan Cuesta (LISA-IPSL) • Valérie Gros (LSCE-IPSL) • Karine Sartelet (CEREA-IPSL)

The theme COMPOSAIR, short name for "Atmospheric composition and air quality", focuses on describing and understanding the formation and evolution of chemical compounds in the atmosphere from the boundary layer (air quality) to the stratosphere. COMPOSAIR focuses on understanding the life cycle of chemical compounds that impact health, ecosystems and the climate, such as ozone, aerosols, but also precursor compounds such as nitrogen oxides or volatile organic compounds. These compounds are reactive and their transformations (photochemistry, aqueous chemistry, formation of secondary aerosols, etc.) are strongly influenced by environmental conditions. In situ observation, remote sensing and modelling approaches are used. Areas of study range from the street scale to the continental scale.

Structure of the research community. COMPOSAIR brings together 7 laboratories (CEREA, LATMOS, LERMA, LISA, LMD, LSCE, METIS) representing about 140 researchers, engineers and technicians. Several other laboratories or institutions, although not officially part of COMPOSAIR, are associated with its activities through collaborations.

Major tools and projects: Research activities are based, among other approaches, on a combination of important measurement and modelling tools. Measurements includes long-term gases and aerosols observatories (including the SIRTA/Saclay station which belongs to the european research infrastructures ICOS (greenhouse gases) and ACTRIS (reactive gases, aerosols and clouds)), a large spectrum of field-deployable instruments as well as remote sensing of the atmospheric composition based on spaceborne measurements, and finally a simulation chamber (CESAM) allowing a better characterization of single-phase or multiphase chemical reactions in the laboratory.

The data from these instrumental platforms are used as constraints for the models developed within COMPOSAIR and which represent the emissions (OLYMPUS multi agents model) and the transport of pollutants and atmospheric chemistry at different scales: From the global scale with the LMDz-INCA model, down to the regional scale with POLYPHEMUS and CHIMERE platforms (used daily for air quality forecasting in France), and to the local scale with Gaussian models, the MUNICH street network model and the computational fluid dynamics code Code_Saturne. Box models are also designed for explicit gaseous chemistry (GECKO-A) and for aerosol modelling (SSH-aerosol). The personal exposure model EXPLUME represents exposure in microenvironments.

Major advances in the field. A major momentum that has been structuring the community for the last couple of years is the organisation of a multi-project (ACROSS, sTREEt, H2C), multi-platforms, multi-instrumental, multi-sites international field campaign in summer 2022 in Paris and its surroundings in order to better understand aging processes in transport situations leading to the mixing of urban pollutants (dominated by anthropic species) and biogenic species (mainly emissions from the vegetation). This effort brings together around 20

laboratories and 100 researchers. Multi-scale modelling tools are used to represent the evolution of concentrations from the street to the regional scales, and to improve the representation of several processes in the model using the observations.

In addition, please find here only a subset of major recent advances, which does not reflect all the work done by the community:

- Recent multi-scale modelling work has made it possible to better understand the population's outdoor exposure to pollutants. Thus, the study of several ambitious scenarios for renewing the composition of the road fleet over 10 years shows that the Parisian population remains exposed to excessively high levels of particles.
- New numerical methods have been designed in order to reduce numerical diffusion in CHIMERE (a common drawback of Eulerian models), allowing for a more realistic description of volcanic plume structures, with a large influence on the SO2 oxidation paths into sulphates.
- In order to reduce uncertainties on the sources and formation of secondary aerosols in the cold and dark Arctic winter conditions, a major international measurement campaign took place in Fairbanks, Alaska during January-February 2022 (ALPACA campaign - Alaskan Layered Pollution and Chemical Analysis).

Activities - Period from July 1, 2021 to June 30, 2022

Composair has built on the momentum created by the summer 2022 Paris campaigns to launch several projects on key questions regarding atmospheric chemistry and its impacts involving additional measurements of:

- Ultrafine particles are ubiquitous and poorly monitored and are a great human health threat.
- Black carbon, which has sanitary and radiative impact
- NH_3, an important precursor of secondary inorganic aerosol
- Secondary organic aerosols characterization through markers measurements and fine speciation of VOCs
- Pesticides can be found in urban centres and have important health impacts.

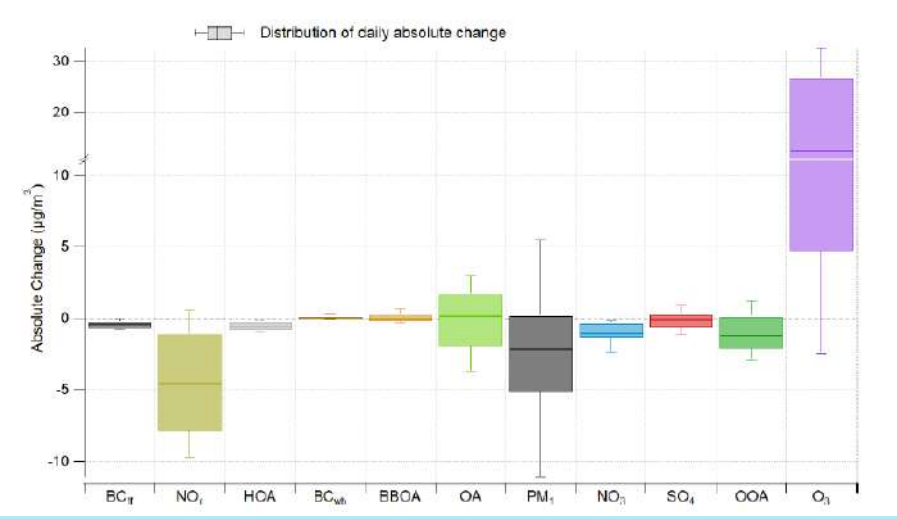
Biomass burning impacts on atmospheric composition. Structuring activities led by Composair, including a workshop, allowed drawing a very interesting state-of-the-art of a large diversity of IPSL scientific activities associated with vegetation fires and atmospheric composition. Scientific axes federating several IPSL laboratories were identified: smoke plume injection heights, multi-species emission factors and radiative impact of smoke aerosols. Research activities on these topics are newly supported by the IPSL through, for example, funding a short postdoc for a collaboration of 3 IPSL labs and the creation of a working group “fire” at the IPSL.

Several groups of IPSL-COMPOSAIR have led and participated in studies for estimating the impact of lockdown from the regional to the global scale. Some of these studies are briefly described here:
In the boreal spring of 2020, strict lockdowns were put in place globally to stem the spread of the Covid-19 virus. They have led to unprecedented reductions in automobile traffic and industrial activity, sharply decreasing emissions of anthropogenic pollutants and inducing significant changes in the composition of the atmosphere from the city scale to the hemispheric scale. This was a rare opportunity to investigate atmospheric chemistry in never-seen conditions.

Based on ammonia measurements made at Paris center and from IASI satellite, Viatte *et al.* (2021) have shown the importance of long-range transport on particulate levels in Paris during the lockdown period and have suggested that ammonia was not the limiting factor of the formation of ammonium nitrate.

Petit *et al.* (2021) have investigated the lockdown impact in Paris region on various gas and aerosols by comparing the concentrations of these pollutants of each day of spring lockdown 2020 to the corresponding meteorological analogue days from the 9 years' dataset obtained at the SIRTA station (20 km south-west from Paris). Results are presented in the figure below.

Menut *et al.* (2020) use chemistry-transport modelling to show that the lockdown effect on atmospheric composition, in particular through massive traffic reductions, has been important for several short-lived atmospheric trace species, with a large reduction in NO_2 concentrations, a lower reduction in Particulate Matter (PM) concentrations and a mitigated effect on ozone concentrations due to non-linear chemical effects.



Using an unprecedented synergy of satellite observations, in situ measurements and chemistry-transport models, Cuesta *et al.*, (2022) have quantified the changes in ozone pollution in Europe associated with the first lockdown in 2020. They highlighted a large reduction in background ozone pollution in rural regions and an increase in ozone pollution in more urbanised regions, especially in central Europe, linked to a reduction of a sink of this pollutant.

Solar Systems

Theme leaders

Nicolas Fray (LISA-IPSL) • Emmanuel Marcq (LATMOS-IPSL)

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).

Various computer 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 GCM, as well as laboratory simulations aimed at reproducing the exotic conditions in the solar system and in exoplanets.

We are involved in the scientific team on some past and present space missions (Rosetta, Venus Express, Mars Express, Insight, Curiosity, BepiColombo, MAVEN, 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: **WISDOM** and **MOMA** part of the ExoMars rover that will analyze the subsurface of Mars; **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.

- Characterization of the organic content of the Martian soil and of the cometary particles thanks to the SAM and COSIMA instruments on board Curiosity and Rosetta missions.
- Selection of 3 new Venus missions (DAVINCI, VERITAS, EnVision) by NASA and ESA.
- Observations of Mercury's tenuous atmosphere, including species not observed since the last encounter by Mariner 10 more than 40 years ago, by the UV spectrometer PHEBUS during the first flyby of Mercury by BepiColombo.
- Numerical simulation of a GCM coupled with dynamic ocean to discuss the stability of an ocean in a cold climate environment in agreement with the geological record.

Main limitations. IPSL does not encompass all laboratories in the 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 and diplomatic context).

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

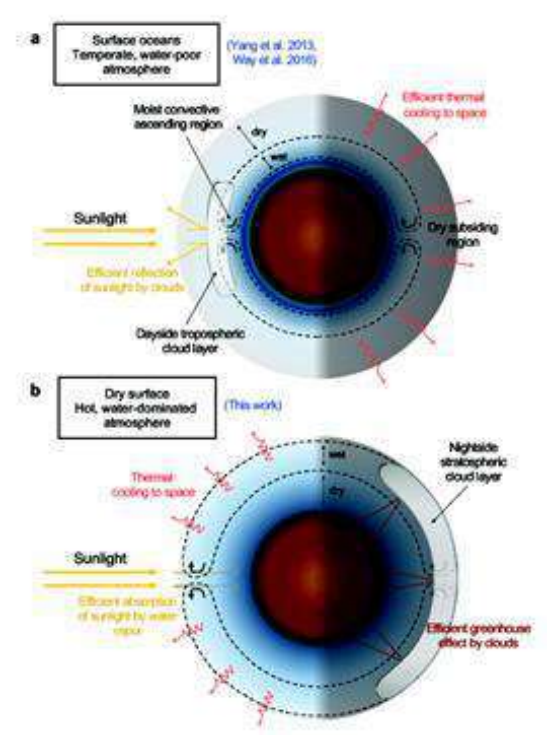
Activities - Period from July 1, 2021 to June 30, 2022

- Detection of new organic molecules in the martian soil thanks to derivatization experiments (Millan *et al.*, 2022)
- Evidence of the link between a regional dust storm and the water escape from measurements of different atmospheric parameters including the dust opacity by MRO, the mesospheric water vapor by TGO and the hydrogen UV emission by MAVEN (Chaffin *et al.*, 2021)
- Why oceans may never have formed on the surface of Venus (Turbet *et al.*, 2021)
- Ocean stability on Mars 3 Gy ago. Numerical simulation of a GCM coupled with dynamic ocean to discuss the stability of an ocean in a cold climate environment (Schmidt *et al.*, 2022)
- Dynamic of tsunamis deposits on Mars (Di Pietro *et al.*, 2021)

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 Full Time Equivalent per 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…)

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”.

Day–night cloud asymmetry prevents early oceans on Venus but not on Earth



Martin Turbet, Emeline Bolmont, Guillaume Chaverot, David Ehrenreich, Jérémy Leconte, Emmanuel Marcq

This paper shows, using three-dimensional global climate model simulations of early Venus and Earth, that water clouds – which preferentially form on the nightside, owing to the strong subsolar water vapour absorption – have a strong net warming effect that inhibits surface water condensation even at modest insolations (down to 325 W/m², that is, 0.95 times the Earth solar constant). This shows that if all of Venus' water inventory was delivered at the time of planetary formation, it could never condense and that, consequently, oceans could not form on the surface of Venus.

Furthermore, this shows that the formation of Earth's oceans required much lower insolation than today, which was made possible by the faint young Sun. This also implies the existence of another stability state for present-day Earth: the 'Steam Earth', with all the water from the oceans evaporated into the atmosphere.

The group has published 77 publications, including: 4 *Nature Astronomy*, 1 *Nature*. Full list in appendix.

Statistics for Analysis, Modeling and Assimilation (SAMA)

Theme leaders

Adriana Coman (LMD-IPSL) • Cécile Mallet (LATMOS-IPSL) • Soulivanh Thao (LSCE-IPSL)

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.

Structure of the research community

SAMA has historically been grouped around 3 sub-themes: data assimilation, statistics, neural network, that's why the theme has three co-coordinators (Adriana, Soulivanh, Cécile). 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.

Major structuring projects

The SAMA group has not structured 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 fifteen 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. For SAMA, it is the opportunity to bring together people from IPSL who work on statistics and machine learning around the issue of extreme event attribution and to establish links with other research institutes abroad that also work on data-sciences for environmental issues.

ARGONAUT - PollutAnts and Greenhouse Gases EmissiOns MoNitoring from SpAce at high ResolUTion (ANR-19-CE01-0007)

In this project, 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. The ARGONAUT project allows the teams working on variational assimilation at IPSL (LSCE, LISA, CEREA) to join their efforts to improve from a methodological point of view the variational data assimilation method by taking into account simultaneously the co-emitted species and also using a new non-local metrics to compare simulated and observed plumes in order to solve the problem of particular plume displacement errors.

Partnership. CEREA, INERIS, LSCE, LISA.

- Major recent advances in the field from the IPSL community
- Opportunities and limitations in the theme
- Main orientations (in a few sentences)

The actions carried out in the SAMA theme aim to create a dynamic of transdisciplinary research. In the coming years, it will be a question of identifying concrete problems in climate science in connection with the key issues of statistical learning.

Activities - Period from July 1, 2021 to June 30, 2022

This section is focused on the past year (if major results arrive in May, there will be a possibility to revise, but we need to complete this section by 22 April):

- 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 AI4Climate seminars. List is available at 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/);
- workshop "Machine learning and uncertainties in climate simulations", 6-9 June 2022. This workshop will investigate how to assess, model, and combine these uncertainties within statistical and machine learning methods. https://www.lebesgue.fr/en/Climatesim;
- 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 in 2022.

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

IPSL Virtual School: Climate Change: Challenges and Issues in Data Science, May 16-19, 2022. The program includes scientific webinars and online discussions on a range of climate science topics, with a focus on Data science and their use for societal and research challenges.

Poster session organized with the Sorbonne Center for Artificial Intelligence from the studies carried out during IA for Climate multidisciplinary research Master internships

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

IPSL

Activity Report

July 2021 • June 2022