L – IPSL LABEX

PROGRESS REPORT AND ACTION PLAN DECEMBER 2017

This document summarizes past projects and results in current projects of the LABEX L-IPSL program. It describes research, innovation and expertise transfer and education achievements and proposition until 2019. It is an update of the 2016 action plan.

Informations are also available from the programme web site: http://labex.ipsl.fr (mostly in French)

V2 –
2017/12/02

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1. General aims of the L-IPSL program

The L-IPSL LABEX is a climate change program hosted by the IPSL federation.

The project, as it was approved by the "Investissements d'avenir", has 3 interlinked dimensions:

(a) A project to accelerate research in a few directions which are key to improve our assessment of future climate change (but reversely do not encompass the totality of the IPSL research).
(b) A project to enhance educational actions on climate change.
(c) A project to favor transfer innovative activities from the IPSL to external partners, including emerging companies.

Although their aims differ, there is of course a necessity to maintain a strong consistency between those actions. This document describes mostly the projected research agenda of the LABEX. The interactions between this research agenda and the educational and innovation activities are also underlined.

The program started in September 2011. The agenda of the LABEX was structured into 3 phases as illustrated below (see Figure 1 below):

- **an initial phase (2011 – mid 2012) where three programs were proposed in order to (i) invite foreign scientists to start working on key issues (ii) initiate or develop collaborations between IPSL and the two new laboratories , and (iii) strengthen IPSL infrastructures (modeling and data bases) which are required for the future LABEX work,**
- **a mid-term phase (mid 2012 –2014) where research projects are developed; this accounts for all projects started in this period, but projects can continue 1 or 2 years after**
- **a long-term phase (2015 – 2020) where 4 major projects are implemented**

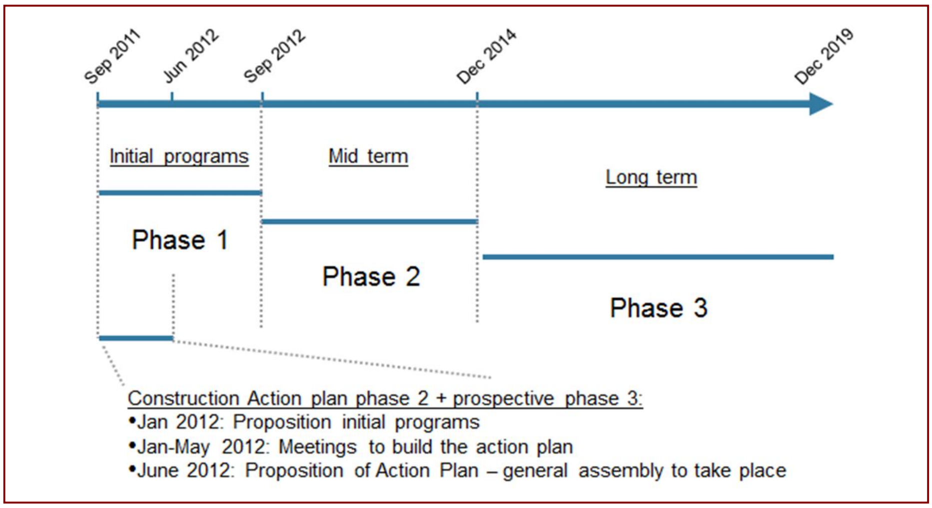

Figure 1: Schematic phases of the LABEX program

The LABEX has been granted for a follow-up to be considered along the IPSL Climate Graduate School. The program will only be deployed starting in 2018, and should follow the proposal that was made in the spring of 2017. This guarantees the continuity of the L-IPSL actions, and actually very much strengthens links between education and research, as well as the education program itself.

2. Research activities

2.1 Research objectives

The LABEX project aims at addressing the following key (broad) questions

(1) How far can we robustly anticipate the future evolution of the atmospheric composition, which depends on a very large number of factors including socio-economic drivers?

(2) How can we determine what is actually predictable in terms of future climate evolution, in a system that combines anthropogenically and other externally induced changes and natural fluctuations?

(3) What are the relations between the global evolution of the climate and its regional consequences?

(4) How much do these local or regional climate evolutions impact environmental resources such as freshwater availability, air quality, and oceanic and terrestrial ecosystem services including the maintenance of biodiversity?

(5) How can we assess the potential impact of unpredictable "climate surprises" that may result from the rapid non-linear behaviour of Earth System components?

Research is currently structured into four main major projects that are described below.

2.2 Summary of results until end of 2017

So far, the L-IPSL has achieved major steps towards its objectives. Research actions have been conducted on key issues to better quantify natural forcings of the global climate, to extend global carbon cycle knowledge and modeling, to set up methodologies for understanding uncertainties, or providing technologies to better understand the natural variability and abrupt climate changes. It has also substantially improved the analysis of climate variability, processes and future projections including impacts from the CMIP and CORDEX international exercises. This has required the development of an integrated data facility for climate simulations, now recognized worldwide. Thanks to the LABEX funding, as of December 2017, **98** articles have been published or are accepted so far, among which **13 in Nature and PNAS family journals**. **More than ten foreign scientists** have been invited to visit the L-IPSL laboratories through L-IPSL funding on total. **More than twenty post-doctoral researchers or engineers** have been hired to conduct the research program, about a half of which coming from a foreign university. **Twenty** projects have started so far, linked to one or several post-doctoral position. The LABEX allowed the creation of open-access data bases and information web sites, such as the climate proxy database, a database collecting observations in the Arctic area and a large public communication web site on climate change.

Since 2015, four new large projects are being developed for the last L-IPSL phase until 2019, focusing the strategy on strongest activities:

- putting together simulations and observations to understand abrupt paleoclimate variability,
- understanding 20th climate variations,
- understanding climate change impacts emergence,
- developing climate models.

The summary of the results of the mid-term phase projects was given in the previous Action plan and is not repeated here. We focus in this report on the new large projects which are currently in development.

2.2.1 Brief overview of mid-term projects

For research the mid-term phase strategy was to develop a limited number of key projects that involve several laboratories of IPSL, solve important questions while strengthening the interactions in the IPSL community and the common tools, and initiating collaborations for larger projects funded by other instances (EU, ANR, …). The actions were pursued whenever possible over several years in order to consolidate teams and tools, and benefitting from the unique long-term framework of the LABEX.

Table 1 summarizes the 16 projects that were developed in the mid-term phase. A description of the projects can be found on http://labex.ipsl.fr/recherche/actions-scientifiques. A few highlights are summarized on http://labex.ipsl.fr/recherche/highlights.

Project number and short title	P.I. + date decision	Contact CR & WP	Dates & Status	Short description
1 Carbon in rivers	P Ciais 2012	A Ducharne WP1-WP4	Jul 2013 – Jun 2015 ongoing	2-Year post-doc Modeling the C cycles in rivers with ORCHIDEE
2 Volcanism	M Khodri 2012	E Guilyardi WP2	Sep 2013 – Aug 2015 ongoing	2-Year post-doc Climate impacts of volcanism in the last millennium and modeling
3 Impact indicators	B Sultan 2012	P Braconnot A Ducharne WP4-WP3-TWP3	May 2013 – Apr 2015 ongoing	2-Year post-doc Construction and evaluation of climate impact indicators
4 Chronology	A Landais 2012	F Bassinot WP5	Oct 2013 – Sep 2014 ongoing	1-Year post-doc (+6 month) construction multi-archive chronologies
5 Arctic portal	K Law 2012	K Law TWP2-WP3	Sep 2013 – Aug 2014 completed	1-Year engineer arctic data portal gathering data & information
6 Isotope database	V Masson-Demmotte 2012	C Colin TWP2-WP5	May 2013 – Apr 2014 extension 5+6 months	1-Year (half time) post-doc Web portal on data paleo archives +5 month + 6 month
7 CMIP5 data	S Denvil 2012	JL Dufresne TWP1	Oct 2013 – Sep 2014 Completed	1-Year post-doc Facilitation of access to CMIP5 data
8 W Africa Climate change	S Bastin 2013	F Hourdin WP3	Oct 2014 – Sep 2016	2-Year post doc How climate models simulate W African climate
9 Climate sensitivity and clouds	S Bony 2013	JL Dufresne WP2	Sep 2014 – Aug 2015 ongoing	1-Year post-doc on cloud feedback processes in the LGM
10 Migrations of Zooplancton	L Bopp 2013	M Gehlen WP1-TWP1	Sep 2014 – Apr 2015 ongoing	8-month post-doc on carbon cycle and migration of zooplankton

11 IPSL-CM6	O Boucher & JL Dufresne 2013	JL Dufresne TWP1	Mar 2014 – Feb 2015 ongoing	1 year Post-doc on radiative transfer modeling, 0.5 year on air-sea coupling
12 Stretched model version	JL Dufresne & F Hourdin 2012	JL Dufresne TWP1	Oct 2014 – March 2014	6 month post-doc to develop and customize the use of a stretched version of IPSL-ESM
13 SIRTA data reconstruction	M Chiriaco 2013	M Haeffelin TWP2	Nov 2014 – Oct 2015	1-Year engineer on reconstructing all data from archived SIRTA observations
14 Impact of dust on IR radiation	P Formenti 2014	B Marticorena WP1	Oct 2014 – Sep 2016	2-Year post-doc on determining the IR radiative impact of dust aerosols
15 Impact of CC on river nutriments	V Thieu	C. Rabouille WP4		1.5-year post-doc on impacts of CC on river nutriments
16 Ocean acidification	D Dissard	C. Colin WP4-WP5		1.5-year post-doc on impact of CC on acidification

Table 1: Research projects of the mid-term phase of the LABEX. Colors denote the time when projects were decided (orange=PA2012; blue=PA2013; grey=PA2014; pink=extensions asked in PA2014; darker grey=project has been extended for a few month beyond end of 2016).

2.2.2 List of funded visits in the mid-term phase

The LABEX also supported the visit of several scientific foreign colleagues during the mid-term phase, with implications in the LABEX work packages. These are summarized in Table2.

Visitor (Institution)	Dates	Work Package	Short description
V. Balaji (GFDL)	Jun-Sep 2015	TWP1	V Balaji ,leader of GFDL modeling team, visited IPSL climate modeling centre during 4 months (june 2015-eptember 2015). During this period, IPSL was strongly involved in the preparation of CMIP6 trough different actions : - the preparation of the next release of IPSL climate model : IPSLCM6 - the participation to CMIP6 protocols including WIP activities - the securisation of computing and storage ressources required for CMIP6 at IPSL V Balaji accompagnied IPSL teams during 4 months and help us to understand our strengths, weaknesses, opportunities and threat related to all of these topics. V Balaji compared GFDL and IPSL work processes regarding model evaluation, model construction, model improvement with a focus on man power and man motivation. He participated to a dozen of IPSL internal meeting devoted to the preparation of IPSLCM6 (LMDZ, IPSLCM6 and IPSL platform environment). He participated also to a couple of IPSL scientific meeting : XXst reconstruction, LMD climate team. He met with French Supercomputers centers and with IPSL sponsors and recommended us to increase our local IT ressources to secures CMIP6 analyses. He finished with a seminar, memorable for all participant and very inspiring for all IPSL climate modeling center members.

N. Cassar (Due Univ.)			Nicolas Cassar a une expertise internationalement reconnue pour la mesure de le production biologique nette dans l'océan (NCP) (développement de mesures en continu sur bateau du rapport Oxygène/Argon par spectroscopie de masse; Cassar et al. 2009) et a acquis une base de données très importante (Cassar et al 2007, Chang et al. 2013). Les équipes du LOCEAN collaborent avec lui, notamment sur la comparaison des mesures de NCP et la variabilité interannuelle des flux air-mer de CO2. Lors de sa venue au LOCEAN/IPSL, N. Cassar a travaillé, en collaboration avec les équipes concernées, sur la NCP dans l'océan sud, sur des indicateurs de déclenchement de la floraison printanière et sur l'analyse des processus en jeu dans différentes régions de l'océan. Ce travail a contribué en partie à l'article Cassar et al. 2014.
A. Evan (Scripps IO)	1-31 July 2015	WP3	Dr A Evan collaborates with LATMOS. Sahara Heat Low forced winds and their impact of dust variability at decadal scales. Analysis of past, present and future dust in West Africa based on the orographically-forced mode of 10 m winds over the Sahara.
M.-J. Gaillard (Linnaeus University, Kalmar, Sweden)	31/08/2015 – 30/10/2015	WP5	*Prof M-J Gaillard* collaborates with A.-M. Lézine and K. Lemonnier at LOCEAN. During her stay, MJ Gaillard has developed several projects in climate reconstructions from pollens. She has given two lectures and participated to several workshops. From her visit, two articles are underway.

2.3 Large Projects

IPSL has a number of advantages compared to other international climate research centers: its ability to address issues in a comprehensive manner on all compartments of the climate system, understanding the variability of climate on various scales time (past and future) via simulation, observation and paleoclimatic reconstructions, its ability to analyze forcings, feedbacks, and impacts of climate change (CC) on some sectors of society or some natural environments.

A strategy has been defined in 2014 on issues that the LABEX should focus over the last half of the program. It was proposed that IPSL build three ambitious projects, involving all WPs LABEX, for the last part of the LABEX (until 2019):

LP1) Investigating, from observations and modeling, steep interglacial climatic changes of the last ice age (MIS3) and the last interglacial maximum.

LP2) Understanding of 20th century climate and the allocation of its variability, by reconstructing its forcings and a set of simulations

LP3) Investigating the emergence of a few impacts and associated uncertainties

In addition the L-IPSL pursue its support to the global climate model development, under a 4th project

LP4) Climate model development

These “large projects” are detailed in the following sections, as well as their intermediate results.

Finally, the LABEX has opened a call for invitations of foreign senior scientists for short visits (up to 3 months). A first call was issued in 2017 and another call will be launched in 2018. Eight scientists should visit IPSL during the 2017-2018 period, calling for an extension of the budget, which is notified in the Table 3. The new (and last) call that will be issued in 2018 will cover only 3 visits (budget 30 000 euros).

2.3.1 LP1: Abrupt and large climate variability

Project leads: Christophe Colin (GEOPS) & Amaëlle Landais (LSCE)

Participants

Teams	L-IPSL contributors	External collaborators
Marine cores and corals	Franck Bassinot (LSCE) Ioanna Bouloubassi (LOCEAN) Christophe Colin (GEOPS) Delphine Dissard (LOCEAN) Stéphanie Duchamp-Alphonse (GEOPS) Aline Govin (LSCE) Catherine Kissel (LSCE) Claire Lazareth (LOCEAN) Elisabeth Michel (LSCE) Luc Ortlieb (LOCEAN) Marie-Alexandrine Sicre (LOCEAN) Giuseppe Siani (GEOPS) Sophie Sepulcre (GEOPS) Claire Waelbroeck (LSCE)	Renato Salvatteci (Germany) Olivier Esper (Germany) Jeremy Hoffman (USA)
Terrestrial sites	Anne-Marie Lézine (LOCEAN) Sébastien Nomade (LSCE) Hervé Guillou (LSCE) Denis-Didier Rousseau (LMD) Christine Hatté (LSCE) Abdel Sifeddine (LOCEAN) Dominique Genty (LSCE) Dominique Blamart (LSCE) Uli von Grafenstein (LSCE) Amaëlle Landais (LSCE) Anaïs Orsi (LSCE) Valérie Masson-Delmotte (LSCE)	Alexander Prokopenko (USA) Chronis Tzedakis (UK) Sophie Verheyden (Belgique) Russell Drysdale (Australie) Giovanni Zanchetta (Italy) Haï cheng (Xi'an Jiaotong University) Emilie Capron (University of Cambridge) Sune Rasmussen (University of Copenhagen)
Modeling	Pascale Braconnot (LSCE) Didier Roche (LSCE) Masa Kageyama (LSCE) Adriana Sima (LMD) Jean-Claude Dutay (LSCE) Laurent Bopp (LSCE) Yves Balkanski (LSCE) Camille Risi (LMD)	Louise Sime (UK) Marie Jose Gaillard (Sweden) Louis François (Belgium) Tilla Roy (ECOCEANA, France)

Main participants to this project at the writing stage.

Project summary

This project focuses on two aspects of past climate change that are directly relevant for the simulation of future climate change:

1- The last interglacial period (LIG; ~130 000 to 115 000 years before present): warmer climate and mean global sea-level values 5 to 9 m higher than today.

2- The abrupt variability of the last glacial period (LG; 70 000 to 20 000 years before present): succession of rapid climatic changes within decades (temperature increases of 10-15°C in Greenland, large temperature and precipitation changes in the mid to low latitudes).

The goal is to build new databases for the periods of interest, to improve our models as well as their capacity to compare their results with data and perform these comparisons. The strategy follows a model-data approach. Indeed, we proposed to initiate two actions in parallel: (Axis 1) the data synthesis and (Axis 2) the development of model interfaces for tracer representations. These two actions rely on developments previously performed within WP5 in L-IPSL: the isotopic paleo-database (Tim Bolliet, Bolliet et al., 2015) and the multi-archives dating tool DATICE (Bénédicte Lemieux-Dudon and Lucie Bazin, Lemieux-Dudon et al., 2015).

Axis 1 (deliverables D1, D2 + participation to D4 and D5) is dedicated to a compilation and implementation in the L-IPSL paleo database of high- to low-latitude records with their respective dating constraints for the LIG and the abrupt millennial variability of the LG encompassing H2 and/or H4. When needed, targeted missing data are added (sequences of tracers or dating constraints) for key climatic periods or geographic zones. Harmonisation of chronologies is ongoing through synchronization tests in specific geographic zones or by type of tracers using the multi-archive version of DATICE.

Axis 2 (Deliverables D3, D4 + participation to D5) is associated with the implementation of 3 major model interfaces: (1) an interface based on the BIOME4 model so that the iLOVECLIM and IPSL model outputs can be compared to pollen data, (2) an interface for the FORAMCLIM model to be used with both the IPSL and iLOVECLIM models. This will also involve some evolution of the iLOVECLIM marine biogeochemistry model, so that its output can be used as input data for FORAMCLIM and (3) dust in interactive mode for paleoclimate experiments using the IPSL model. Finally, axis 3 aims to compare model outputs and data over the selected time periods (D5) (the LIG and the abrupt climate variability of the LG) with newly built databases from Axis 1.

Progress so far

Axis 1:

Lucie Bazin Troussellier (24-month postdoc position, starting the Nov 3th, 2016, with 4 months of maternity leave). During the first three months of work, Lucie mainly focused on the technical aspects of the project:

- data format for the compilation: Linked Earth Paleo Data (LiPD, McKay and Emile-Geay 2015),
- proxy selection to be included depending on the archives (sediment cores, speleothems, lake sediments), and their resolution.
- construction of the Datice website (https://datice-multi-archives.ipsl.fr).

The compilation work started around the Mediterranean region, as the LIG chronological framework of this region may be well constrained thanks to $\delta^{18}O$ stratigraphies, radiocarbon ages, as well as the identification of numerous well-dated tephra layers. Indeed, based on the identification of several well-dated volcanic eruptions within the compiled continental records (single grain $^{40}Ar/^{36}Ar$ dating), it has been possible to gather 6 absolute age markers for the period 160 -85 ka, and to directly transfer most of these ages to the marine realm due to common tephra layers (Figure 2), thus better constraining the penultimate deglaciation and the LIG in this area.

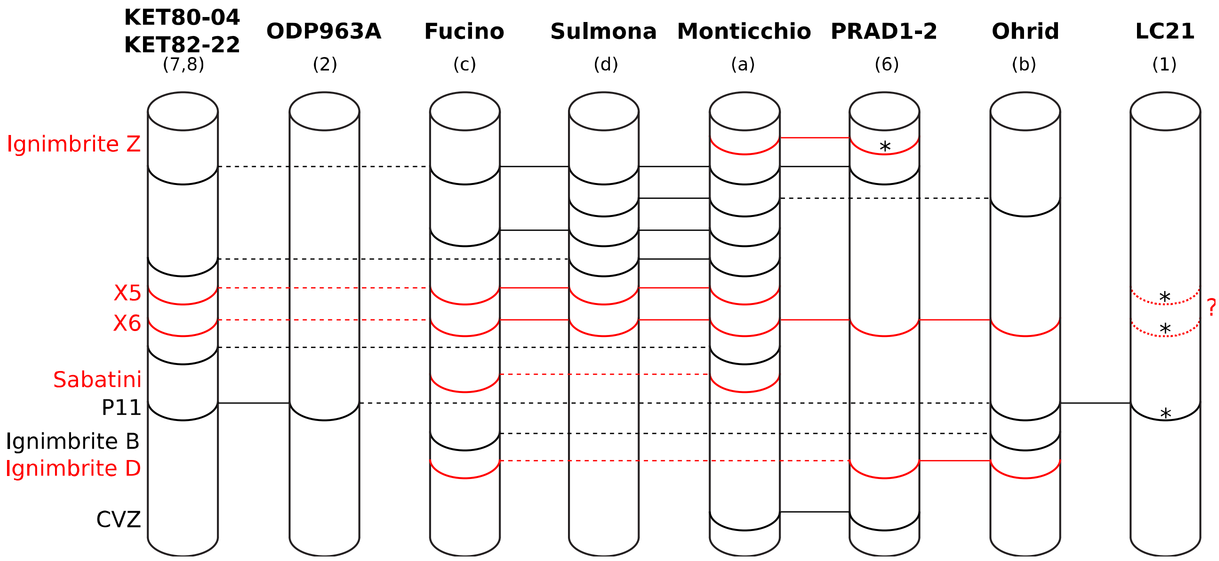

***Figure 1**: Illustration of common tephra layers identified between the continental and marine archives. « * » distinguish cryptotephra layers from the other visible tephra.*

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Temperature-related data were gathered for marine and continental sites:

- temperature reconstructions: micropaleontology (faunal count, pollen), elemental ratios, organic molecules (alkenone, BIT, Tex86)…
- stable isotopes: $\delta^{18}O$, $\delta^{13}C$

As one of the objectives of the data compilation is to build time-slices, it has been decided to compile only records with data resolution **higher than 2000 years during the LIG**. Following these criteria, we selected 8 marine cores and 4 continental sites in the Mediterranean region (figure 1).

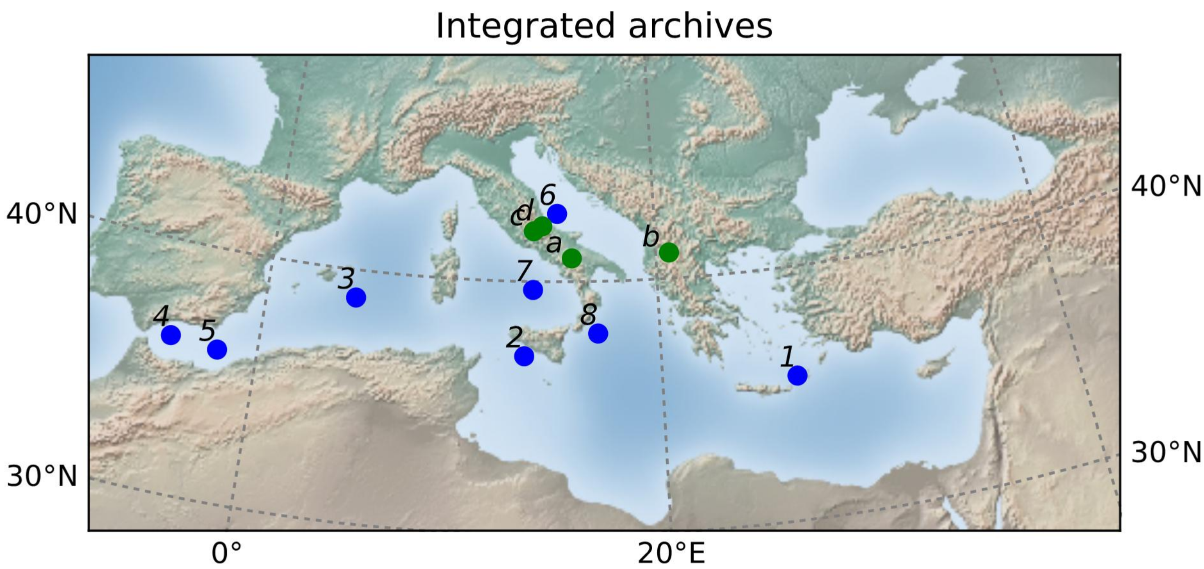


***Figure 2**: Map showing the location of sites integrated in the compilation.*

In parallel, additional micropalaeontological and geochemical data have been acquired on the Southern Ocean (SO) over the last 30 kyrs (M. Brandon, M2). Preliminary results obtained on core MD07-3100 (41°36 S; 74°57 W) highlight the central role of the SO on the global atmospheric pCO_2

changes in the past. Indeed, lower atmospheric CO_2 during the last glacial are associated with relatively low CO_{2aq} conditions in surface waters (lower mass of Noëlaerhabdacea coccoliths), triggering decreased coccolithophore-related Carbonate Counter Pump (lower coccolith calcite mass) and enhanced biological pump efficiency (higher COT/$CaCO_3$ ratio). These results will be published and integrated in the data synthesis for the last glacial period.

Another M2 internship focused on the high resolution sequence of events in the North Atlantic (sea-ice, temperature, changes in Atlantic Meridional Overturning Circulation) over the sequence of Heinrich Stadial 4 in a data – model approach. With this aim, outputs of the IPSL model over an idealized Heinrich event.

Finally, a workshop "Climat and Impacts" has been organized at Orsay the 15th and 16th of November 2016 with sessions dedicated to the model and multi-archives data integration over the periods of interest (session 1: propagation des changements climatiques globaux: processus et rétroactions; session 2: Variabilité climatique décennale à millénaire de l'Holocène et des periods chaudes du passé; session 4: variabilité actuelle et passé du climat des hautes latitudes: role de la cryosphere, rétroactions et impacts).

Axis 2:
Brett Metcalfe has been hired the 1st of April 2017. He started the work on the foraminifera models FORAMCLIM and FAME. A first simulation of the ENSO record in planktonic foraminifera permits to compare the two possible interfaces FAME / FORAMCLIM. This first application also permits to discuss the ENSO signal detectability in various foraminifera species. As an example, the FAME simulation shows that there is a change of the $\delta^{18}O_{calcite}$ and of the simulated temperature induced by variations of seasonality and depth between ENSO and non-ENSO periods but that this change is not significant (Figure 3).

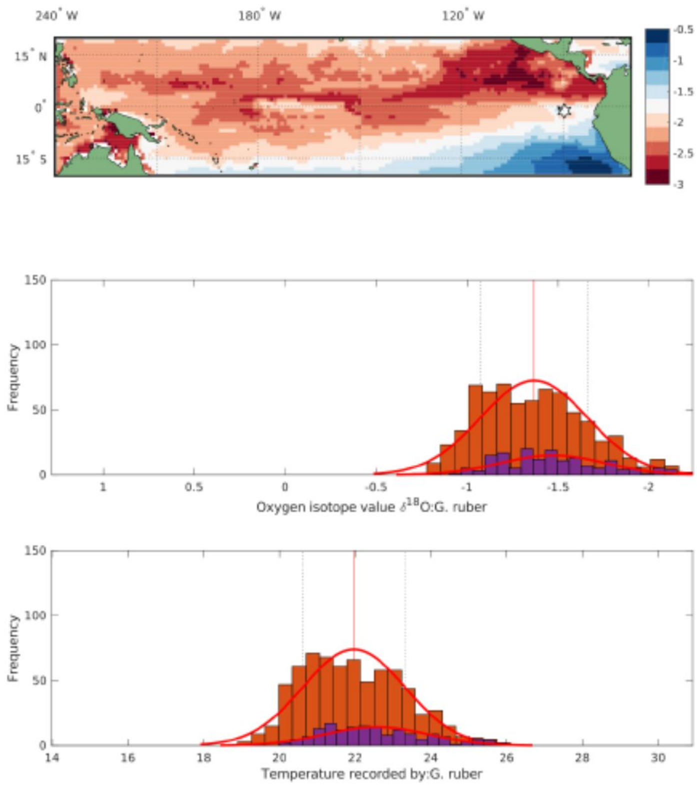


Figure 3: *Simulated distribution of $\delta^{18}O_{calcite}$ and recorded temperature in Globigenoides ruber for El Nino and non-El Nino conditions. Top panel shows the location of the core; the two bottom panels show the distribution of temperature and $\delta^{18}O_{calcite}$ for the full record in purple and for El Nino condition in orange.*

In parallel, tools have been installed to perform vegetation simulation through the BIOME4 model using climatic simulations. The first application (Figure 4) is on the output of the PMIP models for the pre-industrial and the last glacial maximum.

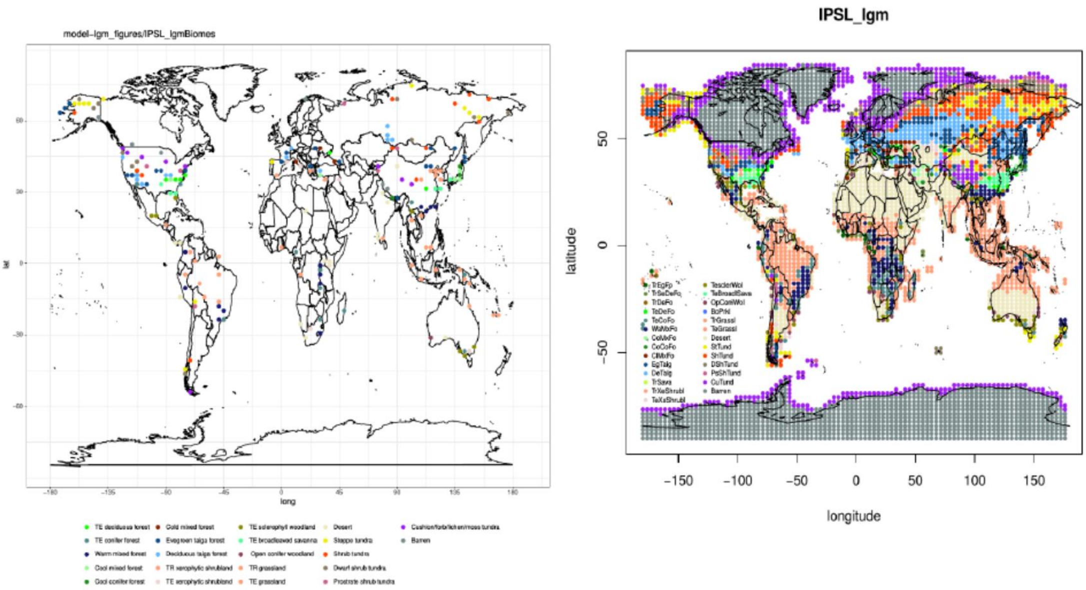


Figure 4: *LGM simulated biomes using the BIOME4 model on the existing data points (left) and for all grid points (right)*

Program until 2019

1- Data syntheses (axis 1)

1-a- Data synthesis of the last interglacial period (November 2016 – April 2018)

We started from the coherent chronology of marine and terrestrial records from the Mediterranean region. We will then extent it to the optimized chronologies of the North Atlantic region, by synchronizing paleomagnetic records (e.g. Blake and post-Blake events) of marine sediments from both regions, checking the coherence of temperature changes to the south and west of the Iberian Peninsula and the coherence with Greenland ice core records.

Once all selected paleoclimatic records are placed on the globally coherent time frame, we will produce time slices for specific time periods to map the spatial distribution of temperature and stable isotopes anomalies.

1-b Data synthesis of the abrupt climate variability

The method for the production of the climatic and environmental sequences is exactly the same as the one given in previous section. We will especially use the paleomagnetic signal around the

Laschamp event (~40000 years before present) for H4 and test the connexion between the Mediterranean region and N. Atlantic region with some available tephras.

2- Model interfaces (axis 2)

2-a Foraminifera interfaces (April 2017 – Dec 2018)

Currently, running FORAMCLIM requires many steps including corrections for present-day biases and grid adjustement. The way FORAMCLIM was written makes its use very time-consuming if we want to use it for long simulations/high resolution model output. The model will therefore be adapted for an easier use with large input files. Moreover, there are a few variables missing from the marine biogeochemistry model implemented in iLOVECLIM that are required as inputs for FORAMCLIM. The objective here is therefore to compute these variables, either by working on the marine biogeochemistry model itself, or by building simple rules from available output from the IPSL model.

2-b BIOME (March 2017 – Dec 2018)

After implementation (see above), we will use the BIOME model in the IPSL-CM to generate outputs that are coherent with pollinic records on the abrupt events of the last glacial period. The tool will also enable the study of the influence of single factors (CO_2, single climate variables) on the vegetation so that the processes leading to its evolution are better understood. The outcome can be compared to more complex dynamical vegetation models such as ORCHIDEE but our aim here is really to build a tool with which we can easily compare with pollen data.

2-c Dust in interactive model for paleoclimate experiments using the coupled model (Jan-Dec 2018)

The configuration LMDZORINCA of IPSL-CM forced by sea surface conditions obtained by the iLOVECLIM model will permit an improved understanding of dust emission and deposition under various climatic conditions. Calibration and validation of the model through results on dust sedimentation obtained within axis 1 will enable us to run the IPSL-CM in an interactive mode with dust. This task will be realised by permanent staff of L-IPSL and does not require specific manpow*er.*

3 - Comparison between model outputs and data over selected time periods (2019).

The exploitation of model simulations and comparison to data synthesis will be performed by master 2 internships with involvement of permanent staff from labex L-IPSL (especially for publications).

Deliverables for 2016-2019

Deliverable D1 - A **well-dated** and **global** data synthesis of the last interglacial (temperature, stable isotopes) with (1) well-dated temporal evolutions of climatic records (with propagated age and tracer errors) and (2) snapshots of climatic state for selected time slices.

Deliverable D2 - A **well dated** (200 years relative uncertainty) and **global** synthesis **integrating new targeted measurements** over two abrupt events of the last glacial period :

- Heinrich 2 : this event occurs in a full glacial context (maximum ice sheet extent, ~ 25 ka)
- Heinrich 4 : this event occurs in an intermediate glacial context (intermediate ice sheet extent, ~ 40 ka)

Deliverable D3 - Integration in climate models of two interfaces for climatic tracers:

- **FORAMCLIM** : an ecophysiological model for growth and distribution of foraminifera (Lombard et al., 2011) to (i) link the relative abundance of various species of foraminifera (a major proxy in marine archive) to climatic parameters and (ii) study the impact of habitat on paleoceanographic records.
- **BIOME** : a biome model enabling the reconstruction of the natural vegetation at equilibrium and a direct comparison to the observed and measured pollen distributions (the BIOME classification has been used in the analysis of many pollen records).

Deliverable D4 - Realistic implementation of the interactions between dust, vegetation and climate in the coupled model in order to run paleoclimate simulation including **dust in interactive mode**.

Deliverable D5 - Model-data confrontation on the key time periods of this project (last interglacial period, one abrupt event in full glacial context, one abrupt event in intermediate glacial context). This will particularly enable us to test the different hypotheses leading to abrupt climatic change (freshwater flux, change of sea-ice regime in northern Atlantic, changes of ice-sheet extent through iceberg discharges, bipolar seesaw or tropical – high latitudes teleconnections, …).

Budget for 2016-2019

Expenses already decided in 2015

Workshops and associated invitation: 4000 euros
- *"Climat et Impacts" workshop (3000 euros)*

Master 2 internships including funding for analyses (1 / year): 2*4 keuros

Post-doc for data synthesis (starting early 2016): 160,5 keuros

Post-doc for modeling (starting early 2016): **160,5 keuros**

Total for 2016 - 2019: 333 000 euros

2.3.2 LP2: Reconstructing and attributing climate variability since the early 20th century

Project leads : Slimane Bekki, Frédérique Cheruy, Marjolaine Chiriaco, Eric Guilyardi, Juliette Mignot *(alphabetical order)*

Project summary (goals, methods)

Understanding, perception and recognition of climate change due to human activities are complicated by internal variability that occurs over a wide range of time scales (from days to several decades). This internal variability arises from the chaotic nature of fluid motions and from the interactions between the components of the climate system (atmosphere, ocean, cryosphere, continents and biosphere). It comes in addition to externally forced variability from both natural (solar activity and volcanism) and anthropogenic sources (emissions of greenhouse gases –GHG, sulfate aerosols etc.). The weight of internal versus forced components increases from global to regional scale (Deser et al 2012). **The overall goal of this project is to understand the relative role of external forcing and internal variability in shaping the climate variations since 1900, at the global, regional and local scales**. For this, we promote reconstructions of the climate over the historical period where internal variability is constrained to observations, taking benefit of the unprecedented amount of high quality observations during the last decades in some specific areas. First, the reconstructions will provide the basis for analysis of the climate at various scales, providing a unique opportunity for identifying trends and processes of decadal variability. Second, analysis performed in this project provide ideal test-beds for reducing persistent biases and systematically testing parameterisation which otherwise remain, in some places, quite empirical. This project also paves the way for the contribution of IPSL to climate services, including the initialisation of decadal forecasts and providing more reliable reconstructions to test the models developed for impact studies.

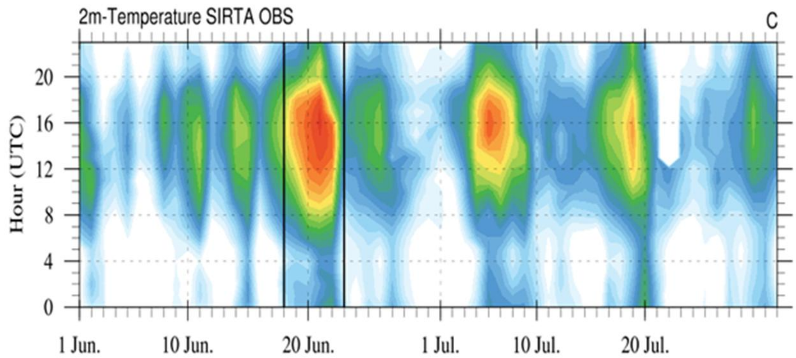
These reconstructions require a detailed review of the external forcings themselves (solar, volcanic, aerosols, dust) as well as a methodological work on how to best drive the model components by observations. This is performed in a first set of tasks (task 1), The second set of tasks (task 2) aims to understand the relative role of external forcing and internal variability in shaping the climate variations since 1900, at the global, regional and local scales. The atmosphere-only reconstructions, a central and common tool within the project, will be further extended (coupled reconstructions, regional simulations, downscaling…) as well as compared to ensembles of free (no nudging) simulations to address specific science questions. The goal is to identify how external forcing influences the statistical distribution of climatic events, in order to understand how these distributions may evolve in the future as external forcing changes. Analysis of the nudged simulations together with observations available at IPSL will also provide test cases for process-oriented evaluation of the model's physics. Hence, task 2 will not only feed from the developments performed in task 1 but it will also feed back to the latter for subsequent improvements. Let us emphasize here that the aim of the project is not to produce an additional climate reanalysis while several centres already do so with dedicated tools. The idea here is to gather expertise and scientific questions around the use of the IPSL climate model, using (among others) the common reconstructions tool for various scientific questions, and feeding back onto the model and forcing implementation developments from different space and time scales perspectives.

Progress so far

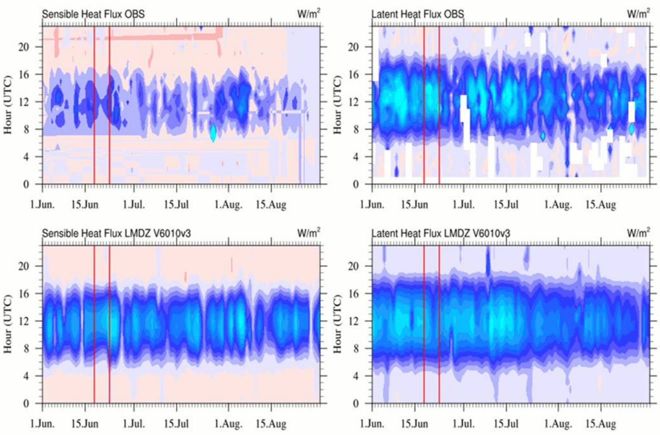
The different tasks of the project are still progressing rather independently. Year 2017 has been marked firstly the development of task 1.2 on the response of the middle atmosphere to solar variability.

Secondly, external collaborators (post-docs) have been recruited in fall for tasks 1.1, 2.1 and 2.3.

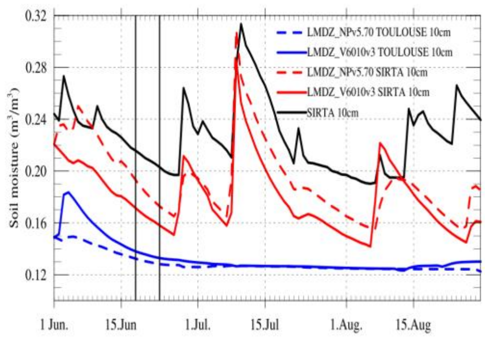
Janfeng Zhao started her post-doc related to **task 1.1** in August 2017. During the first months of her contract she learnt about the LMDZOR model and evaluated the characteristics of the heat wave that occurred in Europe last summer. She compared SIRTA observations with preliminary versions of the climate reconstructions which will be produced with the land and atmospheric physics adopted for CMIP6. The model strongly overestimates the sensible heat fluxes (figures below). It is not clear yet if the differences have to be attributed the processing of the observations or to defect of the representation of surface layer by the model during warm events. In contrast, the reconstruction captures correctly the soil drying which is known to be of great importance in the life cycle of the heat-waves. We will also analyze similar observations recorded in the Toulouse area where the heat wave has been more intense.



Diurnal cycle of the 2m-temperature at SIRTA between 06/01 and 07/30



Diurnal cycle of the sensible and latent heat fluxes observed and simulated at SIRTA.



Time evolution of the superficial soil moisture Simulated and observed during the heat waves

Within **task 1.2**, we have examined the middle atmosphere ozone response to solar variability at various timescales (27-day rotational solar cycle and 11-year solar cycle) using satellite observations and chemistry-climate models simulations. In a first study (Thiéblemont et al., 2017a), we have showed that the IPSL chemistry climate model (LMDz-Reprobus) reproduces a tropical stratosphere ozone response to the 27-day solar cycle which compares very well with the response derived from the UARS-MLS and Aura-MLS observations over two 3-year periods corresponding to the declining phases of solar cycle 22 and 23 (1991-1994 and 2004-2007). This was shown using the nudged version of the model, i.e. where the dynamics is relaxed toward meteorological reanalysis. The comparison of the signals between the two periods also revealed large differences though. To further test the stability of the solar signal, we performed an ensemble of five 15-year simulations in the free-running

configuration of LMDz-Reprobus. We particularly examined the influence of the length of the analysis time window and the phase of the 11-year solar cycle on the retrieval of the 27-day cycle signal in ozone. We found that the uncertainty of the ozone signal estimate significantly increases during minimum phases of the solar cycle and for decreasing size of the time window analysis: a minimum of 3year time window is needed for the 1σ uncertainty to drop below 50%.
In a second study (Thiéblemont et al., 2017b), we have established the first estimate of the 27-day night-time ozone solar signal in the mesosphere and lower thermosphere (50-110 km) using measurements of the satellite instrument GOMOS-ENVISAT (see Figure). Note that at these altitudes, the diurnal cycle largely dominates ozone variations making any other influence difficult to isolate. The observational results were compared with simulations of the high-top chemistry climate model HAMMONIA: it was found that the model strongly underestimates the observed response.
Finally, the ozone response to the solar variability at 11-year timescales was examined in the frame Chemistry-Climate Model Initiative (CCMI) in which LMDz-Reprobus is involved (among more than 10 international CCMs). We found that the CCMs agree well with each other in simulating the 11-year ozone solar signal, further validating LMDz-Reprobus for solar impact studies (Maycock et al., 2017).

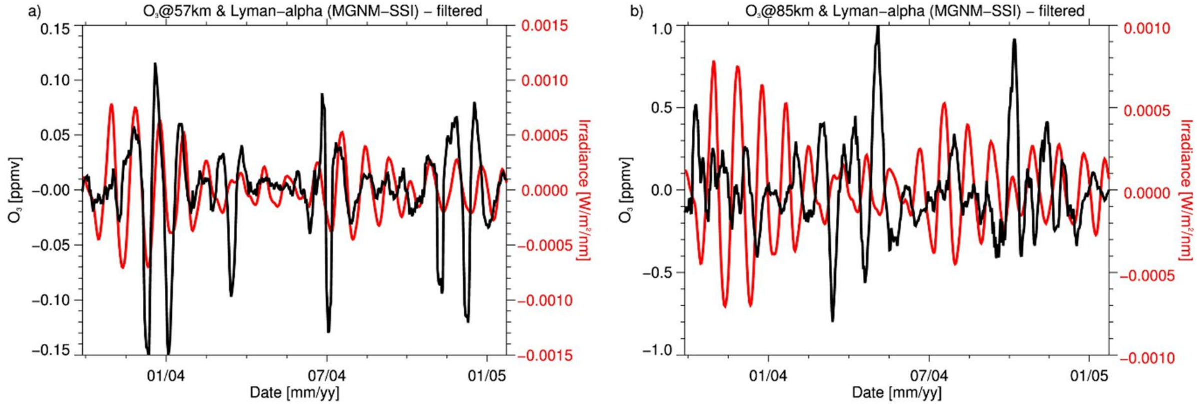


Figure. Temporal evolution of anomalies of (black) Lyman-α line and (red) ozone measured by GOMOS at (a) 57 and (b) 85 km. The time series have been digitally filtered. The solar and ozone variability are correlated in the lower mesosphere (a) but rather anticorrelated in the upper mesosphere (b).

Given the relevance of LMDz-Reprobus to simulate the ozone response to the solar variability, the next step is to investigate the influence of the declining trends detected recently in the solar spectral irradiance (SSI). We will perform LMDz-Reprobus nudged simulations with various SSI trend scenarios and will compare the simulations results with observations to better assess the magnitude of the trend.

As of **task 2.1**, the strategy foreseen was to guide the climate model in coupled mode using the strategy of variable restoring coefficient proposed in a perfect model framework by (Ortega et al 2016). However, this strategy requires the use of sea surface salinity data. Given the lack of such data on long timescales at the global scale, a preliminary set of experiments has been designed in order to test the required temporal and spatial accuracy of salinity data to properly reconstruct the climate decadal variability, in particular in the North Atlantic. These experiments are performed with the low resolution IPSL climate model (IPSL-CM5A-VLR, 2 degrees nominal resolution in the ocean).

Regarding **task 2.3**, the work is just starting as the post-doctorant Justine Ringard arrived on November 1st. She will start her work by characterizing the local variability in terms of evolution and temperature

(Tmean, Tmax, Tmin) and precipitation trends. We also have flow measurements of the Seine watershed. The evolution of these trends will be studied based on reanalysis and long-term meteo-France stations according to first seasons, and second weather regimes

Program until 2019

Tasks 1.1, 2.1 and 2.3 are now ready to take off, and will effectively do so during 2018. 2019 will be the year for linking the different results together. This figure recalls how the tasks depend on and feed each other.

Once the CMIP6 configuration will be frozen, the climate reconstructions based on the atmospheric model will be produced for the 1979-2014 period (task 1.1). We will use it to evaluate the robustness of the thermodynamic component of recent climate. The question being: Once the dynamics is prescribed does the physics behave correctly: For instance, preliminary comparison of the nudged and non-nudged simulations show that the realism of the model is increased in winter and deteriorated in summer for the mid-latitudes. This indicates probably error compensations which need to be tracked and understood. Furthremore, we have been invited to participate to the ExtremeX experiment in the proposed within the “Understand” theme of the World Climate Research Program (WCRP). This experiment aims to disentangle the role of different climatological drivers for recent extreme events, amongst them the large scale circulation and the soil moisture. This will be done by analyzing ensemble of (SST prescribed) free simulations and simulations where the large-scale circulation and/or the soil moisture are prescribed. The simulations will span the very recent period (2009-2015).

Regarding task 2.1, year 2018 will build on the results of the sensitivity study to salinity data to proceed to reconstructions in historical conditions with a nudging towards SST and SSS observations. SSS data will be chosen the various available sources (reanalysis, climatology derived from satellite observations, long-term reconstructions in the Atlantic, Friedman et al. 2017), according to the results of the idealized protocol presented above. Year 2019 will be devoted to experiments using constraints on the wind stress and/or atmospheric winds over the vertical column.

In task 2.3, the temperature and precipitation trends will also be studied at different spatial scales: (i) at the regional scale (Paris region); (ii) at the local scale (pixels around the SIRTA site). These different spatial scales will also make it possible to compare the reanalysis data (ERAI) with the SIRTA data (ReOBS) for the common period.

The most significant changes will be analyzed to understand the processes and feedbacks involved. Indeed, variability is not only explained by large-scale circulation but also by smaller-scale processes. For several years, the number of seasonal anomalies not explained by large-scale atmospheric circulation has increased significantly. For this, the second part of the work requires linking temperature and precipitation anomalies to local processes; using variables available such as radiation, moisture, clouds ... The challenge is to separate the causes of forcing from the climate variability.

Deliverables for 2016-2019

D1.2	Delivery of a set of atmosphere-only reconstructions of the global climate since the early 1950s, earlier if relevant	Task 1.2	
D1.1	Delivery of a set of novel, in-house, physically based solar, volcanic, tropospheric aerosols (e.g. dust) external forcings and implementation	Task 1.1	delivered

	method in the IPSL climate model		
D1.3	Delivery of a protocol for the coupled reconstructions of the global climate for the last decades	Task 2.1	
D1.4	Delivery of publication proposing a validation of the atmosphere-only and coupled reconstructions against observations on the west African monsoon region.	Task 2.2	
D1.5	Delivery of scientific publication on the understanding of climate variability at local scale, over Paris Area	Task 2.3	

D1.1 Delivery of a set of novel, in-house, physically based volcanic aerosols external forcings and implementation method in the IPSL climate model.

The impact of large volcanic eruptions on the stratosphere and climate lies in principle among the potential predicable features of climate after the volcanic eruption took place. However such predictability is hindered by several knowledge gaps regarding the aerosol emission and the climate response. **In a first phase** the microphysical model (*Bekki et al, 1994*) was improved against observations (*CCMI, satellite observations; balloons, etc)* and the computed aerosols radiative properties were implemented in the IPSL model solar spectral bands. **In a second phase**, an ensemble of simulations was performed for major past eruptions (Mt Pinatubo, Samalas, Tambora), using ice-core data to produce realistic scenarios of SO_2 injection into the stratosphere. The uncertainties related to the season of eruption and the altitude of the volcanic plumes deduced from geological evidences were also explored, using dendro-climatological data, historical documents, and improved temperature reconstructions for the last 1500 years. Our approach and modelling framework were tested for several eruptions of the Common Era. For the first time, tree-ring proxies and climate simulations yield similar magnitudes for northern hemisphere summer cooling over land induced by these eruptions, estimated between –0.8 and –1.3°C for the largest eruptions of the last 1000 years. This challenges earlier volcanic forcing reconstruction and results from climate simulations of these eruptions impacts (Stoffel et al, NGEO 2015). **We are currently continuing the development of more accurate histories of past eruptions (see Fig. 1). These developments will be implemented in the last millennium branch of the IPSL_CM6 climate model.**
In addition, a more realistic volcanic forcing is implemented in the LMDz model RRTM radiative code. **These latest developments are now part of the standard version of the IPSL_CM6 model and will be used for CMIP6 simulations.** This promises to improve climate model simulations of natural climate variability due to past and future volcanic events.

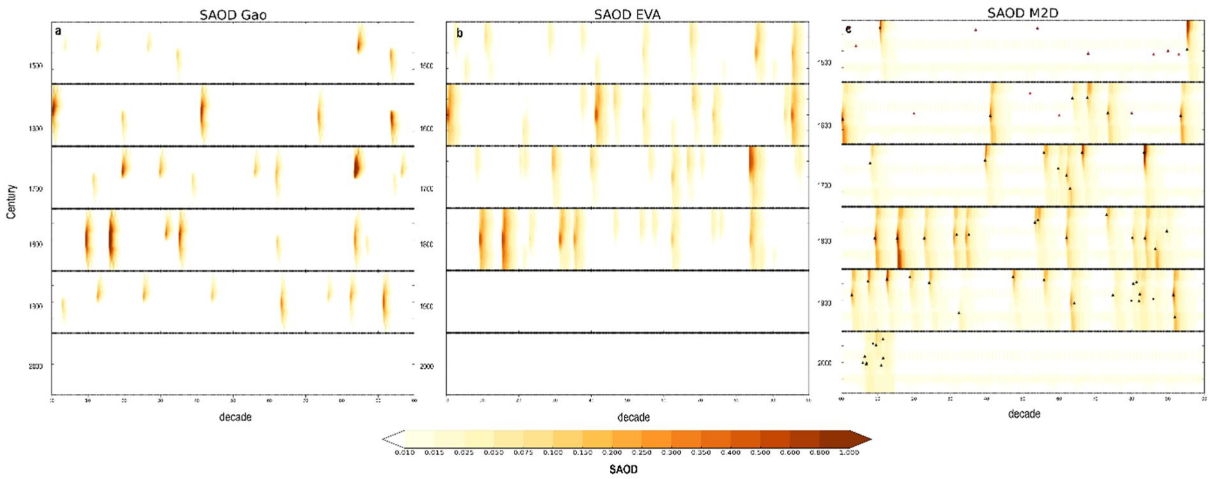


Figure 1. Zonal mean stratospheric aerosol depth as a function of time (x) and latitude (y) from 1500 to 2014 CE period, (a) as provided by Gao et al 2008 dataset which was used in the CMIP5/PMIP3 last millennium experiments, (b) as reconstructed using the eVovl2k volcanic stratospheric sulphur injection estimates and the EVA forcing generator provided by Toohey et al, 2016, and (c) as reconstructed using the IPSL microphysical

model and a bi-polar ice core array for sulphur injection estimates. Triangle marks on panel (c) locate the latitude and time of the eruptions considered in our reconstruction.

Budget for 2016-2019

Staff

Task 1 Task 1.1: Forced reconstructions (Yanfeng Zhao Aug 1st 2017-July 31st 2018) 110 keur
Task 1 Task 1.2.1: Solar forcing (Rémi Thiéblemont April 1st 2016 – March 31st 2018) 110 keur
Task 1 Task 1.2.3: Volcanic forcing (V. Poulain) 55 keur
Task 2 Task 2.1: Methods for coupled reconstructions (Victor Estella-Perez (October 1st 2017 – September 30th 2019) 110 keur
Task 2 Task 2.3: Variability at local scale, over Paris area (Justine Ringard) 110 keur

Staff to be confirmed in 2018
Task 2 Task 2.2: Variability at regional scale (West Africa) 72 keur

Total Staff **567 keur**

Costs related to temporary staff confirmed in 2017
Laptop for travelling purposes x4 (post doc of task 1.2.3 already hired and equipped) **4*2keur**
Attendance to international conferences: 1/ post doc effectively working in 2017 (flight and local transport, subsistence, conference fees) **4*1.5keur**
Publications: 1/ post doc effectively working in 2017 **4*2keur**

Costs related to temporary staff to be confirmed in 2018
Laptop for travelling purposes **1*2keur**
Attendance to international conferences: 1/ post doc (flight and local transport, subsistence, conference fees) **1*1.5keur**
Publications: 1/ post doc **1*2keur**
Total other **27.5 keur**

Publications

Maycock A.C., K. Matthes, S. Tegtmeier, H. Schmidt, R. Thiéblemont, L. Hood, S. Bekki, M. Deushi, P. Jöckel, O. Kirner, M. Kunze, M. Marchand, D.R. Marsh, M. Michou, L.E. Revell, E. Rozanov, A. Stenke, Y. Yamashita, and K. Yoshida, The representation of solar cycle signals in stratospheric ozone. PartII: Analysis of global models, *Atmos. Chem. Phys. Discuss.*, in review, 2017.

Thiéblemont R., S. Bekki, M. Marchand, S. Bossay, H. Schmidt; M. Meftah and A. Hauchecorne, Night-time Mesospheric/Lower Thermospheric Ozone Response to the 27-day Solar Rotational Cycle: ENVISAT-GOMOS Satellite Observations versus HAMMONIA Chemistry-Climate Model Simulations, *submitted to JGR-Atmos*, under review, 2017b.

Thiéblemont R., M. Marchand S. Bekki, S. Bossay, M. Meftah and A. Hauchecorne, Sensitivity of the tropical stratospheric ozone response to the solar rotational cycle in observations and chemistry-climate model simulations, *Atmos. Chem. Phys.*, 17, 9897-9916, https://doi.org/10.5194/acp-17-9897-2017, 2017a.

2.3.3 LP3: Impact of climate change

Project leads: C. Rabouille and B. Sultan

Participants

Teams	L-IPSL contributors	External collaborators
SP1	Marco Gaetani (LOCEAN) Serge Janicot (LOCEAN) Benjamin Sultan (LOCEAN) Ben Parkes (LOCEAN) Dimitri Defrance (LOCEAN) Moïse Famien (LOCEAN) Frédéric Hourdin (LMD) Cyrille Flamant (LATMOS) Mathieu Vrac (LSCE)	
SP2	Christophe Grenier (LSCE) François Costard (GEOPS) Antoine Séjourné (GEOPS) Catherine Ottlé (LSCE) Masa Kageyama (LSCE) Mathieu Vrac (LSCE) Albane Saintenoy (GEOPS) Anne Jost (METIS) as InterFrost participant	Alexander Fedorov (Russie) Pavel Konstantinov (Russie) Ivan Khristoforov (Russie) > 20 InterFrost participants (France, UK, Germany, Sweden, USA, Canada)
SP3	Vincent Thieu (METIS) Marie Silvestre (METIS) Josette Garnier (METIS) Gilles Billen (METIS) Ludovic Oudin (METIS) Goulven Laruelle, (METIS) Christophe Rabouille (LSCE)Laurent Bopp (LSCE) Josiane Ronchail (LOCEAN) Claire Lazareth (LOCEAN) Vincent Chaplot (LOCEAN) Robert Vautard (LSCE) Mathieu Vrac (LSCE)	Pierre Regnier (Belgique) Ronnie Lauerwald (Belgique) Alain Menesguen (IFREMER, France) Chiara Volta (Hawaï)

Project summary (goals, methods)

In 2014, the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) has confirmed that the increase in anthropogenic greenhouse gases emissions has produced (and will continue producing) global climate change with potential impacts on natural resources, ecosystems and human's activities. These impacts and the necessary adaptation of most vulnerable regions are addressed in a separate volume of the AR5 report written by Working Group II “Impacts, adaptation and vulnerability”. As said in this report “Climate change is projected to amplify existing climate-related risks and create news risks for natural and human systems”. It is now clear that Climate change has emerged from natural variability on a global basis for temperature, but changes in precipitation intensity and seasonal patterns do not reach a consensus especially when regional scales are investigated. Yet, the water cycle at the regional scale and its changes are the main drivers that control impact on human populations and ecosystem’s sustainability. Therefore, it is a great challenge to assess at the regional scale the time when **climate change impacts will emerge from present-day climate variability. This is particularly relevant in some regions that are highly threatened by climate change like the Arctic regions, the Mediterranean and for populations from developing countries who highly depend on natural resources like in West Africa.** In this project our goal is to tackle three different types of climate impacts in different regions where IPSL has expertise and L-IPSL initiated activity through previous projects. The large project will build upon these to develop methodologies for emergence of impacts.

Several challenges have to be achieved in the coming decade concerning impacts of climate change. Simulations of regional climate are increasingly becoming available and, combined to impact models, their use to adapt/mitigate the impact of climate change is required in key regions. The assessment of the time of emergence (ToE) for climate change impacts will provide an estimation of the time available before the consequences of climate change become too severe for the humans/ecosystems of vulnerable regions. At L-IPSL, we have targeted three specific regions with impacts of climate change:

- **Sub-project 1: Impact of climate change on water resources and agriculture in West Africa : a time-of-emergence approach**
- **Sub-project 2: Impact of climate change on arctic and subarctic regions : the impacted water cycle from surface to groundwaters**
- **Sub-project 3: Impact of climate change on water quality and aquatic ecosystem services from land to coastal ocean: nutrient and carbon transfer**

The main question raised when mitigation or adaptation is concerned is the time of emergence of these impacts from the variability linked to climate variations. When will these impacts reach a critical treshold? How can human societies or ecosystems adapt to the new situation in a changing climate? Our challenges in Labex-IPSL will be to tackle this issue by implementing these three research sub-projects in a collaborative manner through series of workshops in order to share knowledge and metrics of the Time of Emergence (ToE). The exchange of experience on this common goal applied on different climate change and impacts will strengthen the L-IPSL community working on impact of climate change and deliver a reflexion/methodology to tackle ToE questions.

Progress so far

Sub-project 1 which is the most mature and has started in 2016. Marco Gaetani has been hired as a postdoc in LOCEAN to work on the project on October 1st 2016 for 24 months.

SP1: Impact of climate change on water resources and agriculture in West Africa: a time-of-emergence approach (lead Benjamin Sultan – LOCEAN)

West African climate is dominated by the West African Monsoon (WAM) dynamics and associated summer precipitation. WAM variability ranges at time scales from interannual to multidecadal, and state-of-the-art climate models still struggle in reproducing the historical variability and agreeing on future projections (Biasutti et al. 2013). A particularly relevant issue is represented by the inconsistency between the recent precipitation recovery observed across the Sahelian belt (Fontaine et al. 2011) and the future scenarios projecting a zonal precipitation dipole with wet conditions in central-eastern Sahel and a drying in the west (Monerie et al. 2012). The uncertainties in the model representation of the historical and future West African climate may be attributed to the low skill in identifying and disentangling the numerous drivers of the variability, and the different sensitivity to global and regional drivers (Janicot et al. 2015; Gaetani et al. 2017). Uncertainties affecting climate model simulations are reflected in impact studies, which are based on models outputs (Oettli et al. 2011). **The main objective of this study is the reduction of the uncertainties affecting the definition of the time of emergence of the climate change signal in impacts, through the understanding of the uncertainties in climate models.** The project is progressing following different axes.

1) Identification of key areas and indicators for impact assessment

Agriculture. Running of crop models (ORCHIDEE-crop, SARRA-H, GLAM) forced by climate models outputs. Input variables: 2-m mean temperature, 2-m min temperature, 2-m max temperature, 2-m relative humidity, 2-m specific humidity, 10-m wind, solar radiation at surface, precipitation. Study area: West African countries.

Water resources. Computation of standard water stress indices: (1) wet and dry sequences; (2) Standardized Precipitation Index (SPI, McKee 1993); (3) Palmer Drought Severity Index (PDSI, Dai et al. 2004); (4) Climatic Moisture Index (CMI, Roudier and Mahé 2010); (5) Effective Drought Index (EDI, Roudier and Mahé 2010).

Human Health. Identification of Heat waves. Computation of heat stress and comfort indicators, based on both temperature and humidity conditions: (1) Humidex; (2) Simplified WBGT; (3) Apparent temperature (Zhao et al. 2015).

Renewable energy. Computation of metrics for the estimation of wind power, and solar energy availability (Jerez et al. 2015): (1) Wind power density, estimated by using a wind power curve that establishes the working regimes of a wind turbine; (2) PV power generation potential (PVpot), a dimensionless magnitude accounting for the performance of the PV cells with respect to their nominal power capacity according to the actual ambient conditions.

2) Process-oriented model assessment

CMIP5 climate models have been analysed in assessment of possible biases in representing the mechanisms driving climate change in West Africa. Specifically, the precipitation sensitivity to global warming has been tested in coupled ocean-atmosphere historical simulations and future projections, aiming to identify the sources of uncertainty in the 21st century Sahelian precipitation. During the 20th century, CMIP5 models with strong warming trends simulate weak or negative trend in precipitation. The opposite is simulated in the 21st century, when the stronger is the warming, the larger is the precipitation anomaly. Interestingly, when SST-prescribed atmospheric-only simulations are considered, the hydrological sensitivity in the 20th century is similar to the 21st century. Although not conclusive, results point out possible biases in the ocean response to CO_2 forcing in coupled climate models.

3) Application of climate outputs to impact indicators

Output from CMIP5 climate have been used to force the GLAM model, to simulate crop productivity in West Africa under idealised climate scenarios. Namely, experiments have been run to simulate the yield response to a uniform 4K warming of the global ocean, and to a quadrupling of the CO_2 atmospheric concentration. In addition to the response to the climate variables, the response to the CO_2 fertilising effect has been studied. Results show that a 4K global ocean warming leads to a dramatic reduction of crop productivity in West Africa, associated with surface warming and precipitation reduction. On the other hand, the positive effect on yield of the CO_2 concentration increase is mainly related to the direct fertilisation effect, rather than to the intensification of the monsoon.

4) A time of emergence analysis

By using CMIP5 output from historical simulations and future projections, climate variables and impact indicators have been analysed in a time-of-emergence approach. For climate variables, the estimation of the ToE requires estimates for the climate change signal (S) and for the variability (or 'noise' - N). ToE is defined as the first year in which the signal-to-noise ratio, S/N, crosses particular threshold values (such as 1 and 2), but for certain impacts other values may be more appropriate. Following Hawkins and Sutton (2012): S is extracted by regressing local climate variables and impact indicators onto a smoothed version of the global mean projection, making the assumption that the local changes scale with global signal; N is defined as the interannual standard deviation in historical simulations. In Fig. 1, an example applied to PV power generation is presented. PV power mainly depends on solar radiation, although surface heating reduces PV module efficiency. Wind has a positive effect on PV power, cooling the surface. A ToE analysis for West Africa shows that, even if solar radiation should not change up to mid-century (Fig. 1a), and changes in wind speed will be favourable (Fig. 1b), the negative effect of climate change on PV power will be anticipated by the early change in temperature (Fig. 1cd).

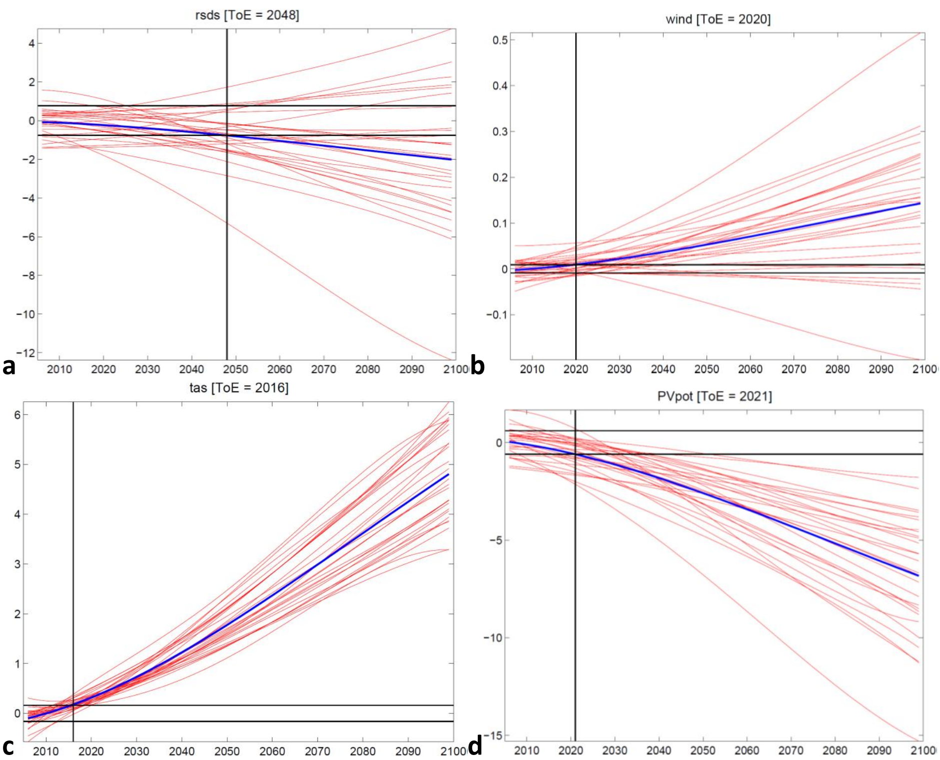


Figure 1. West Africa ToE for (a) solar radiation, (b) 10-m wind speed, (c) 2-m temperature, (d) PV power generation. Red lines are the climate signal for individual models, blue line is the ensemble mean, horizontal black lines show the climate noise estimated from historical simulations, vertical black line is the ToE. CMIP5 are bias corrected by Moise Famien (LOCEAN).

Subproject 2 (SP2) Impact of climate change on arctic and subarctic regions (leader Christophe Grenier – LSCE)

Eric Pohl, a postdoc researcher was hired in July 2017 (for 24 months).

A field site survey on the Syrdakh site in Yakutia (Siberia, Russia) was carried out 10 - 23 September 2017 with Eric and a Albane Saintenoy (GEOPS) in collaboration with the Melnikov Permafrost Intitute (MPI). The overall purpose is to study the ground thermal evolution of a landscape unit in typical of Yakutia in continuous permafrost: a river, its valley, meadow and forested areas. This survey involved the first geophysical campaign and provided fruitful results on distributed ground state and properties and thermal and hydrological evolution (ERT & GPR, active layer depths, ground properties through pits, downloading of temperature and hydrological monitoring). The Syrdakh dataset (2012 – 2017), unique for a river-valley system, is now organized by Eric into a regionalized database. It provides the basis to the simulation (Cast3M code) of the distributed 2D heat transfers within the valley ground (permafrost temperature evolution). The numerical model presently developed by Eric has already showed the potential to represent the thermal evolution of this landscape unit in a realistic way. It will provide the link between surface climate changes and their impact on the permafrost conditions.

Another outcome of our visit at MPI was in collecting meteorological (dating back to the XIXth century) and ground temperature (beginning of the XXth) histories available for the Yakusk region. These histories are being analyzed soon to address issues of CC and ToE (Matthieu Vrac, LSCE). Outcomes of global climate models will be analyzed and compared with these histories to build a realistic climatic scenario on this poorly studied region, and providing a inputs for the final study of ToE of CC.

22 – 23 November 2017 have seen the third workshop of the InterFrost Benchmark project on coupled Thermo-Hydrological models organized by C. Grenier. The recently developed experiments in the cold room (François Costard, GEOPS) were presented. A common simulation phase was decided with a dead line in June for results presentation at the EUCOP2018 meeting (Session organized by Grenier et al.). Eric presented the Syrdakh database in view of future InterFrost tasks. The paper providing the first phase of inter-comparison of codes was accepted by ADWR with minor changes allowing future modelers to run their models against reference simulations (wiki.lsce.ipsl.fr/interfrost).

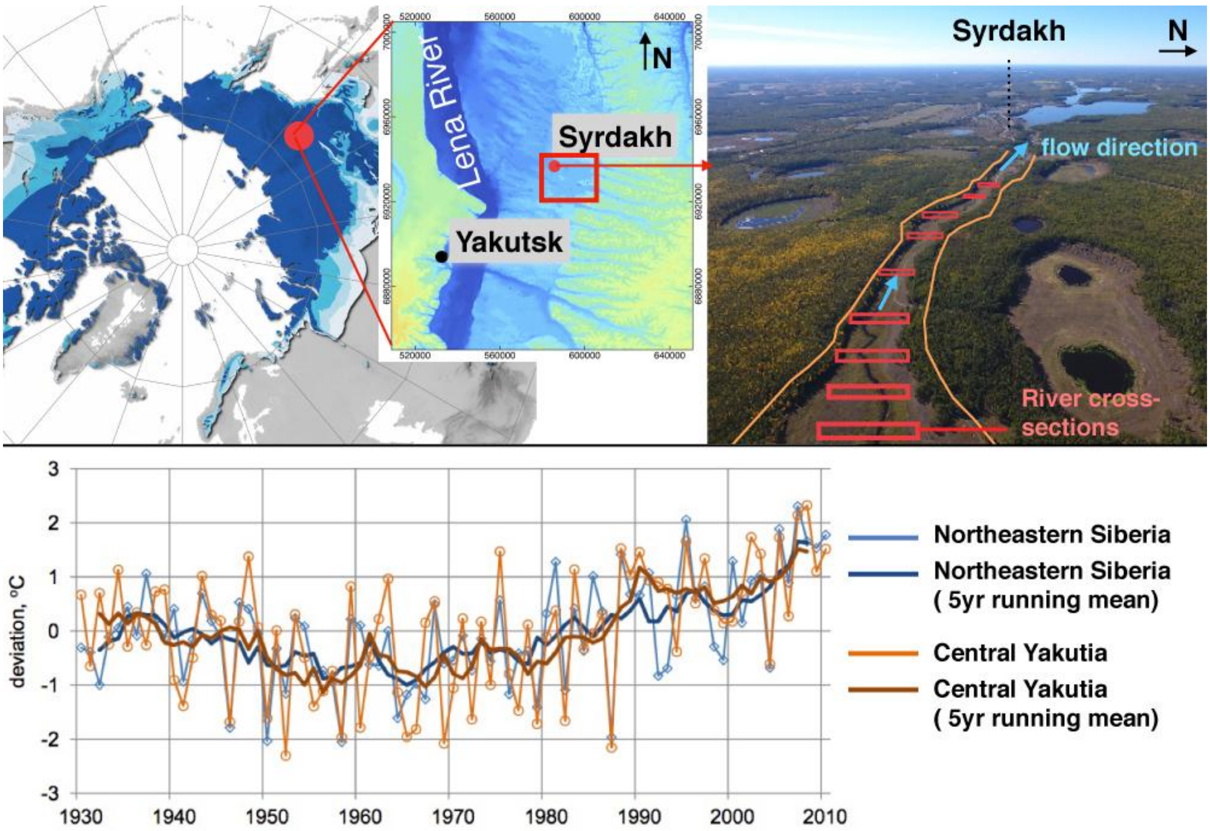


Figure 2: (1) An outline of the frame and a rough representation of the cross-sections of the river. (2) Deviations from the average monthly temperatures of the long historical time series for North-East Siberia and central Yakutia (Figure adapted from Eurasia, AN Fedorov et al., 2014). Geophysical measurements were made in cross-sections (red boxes) and soil pits and samples were taken at selected cross-sections. Time series data are provided by our partners at the Melnikov Institute for Permafrost (MPI)

Subproject 3 (SP3) clearly identifies the need for a regional integrated process-based quantitative understanding of the aquatic continuum in response to climate changes (lead Vincent Thieu – METIS)

Postdoc researcher hired in October 2017 (for 18 months) : Goulven Laruelle

A recent project was launched within the L-IPSL (WP4 project 15) to couple a semi-distributed hydrological model (GR4J-CEMANEIGE; Perrin et al., 2003, Valéry et al., 2014) to a mechanistic biogeochemical river model (pyNuts-Riverstrahler; Thieu et al 2015) and an estuarine 1-D biogeochemical model (C-GEM; Volta et al 2014). Developed in view of a generic application at the continental scale, this modeling chain is has been first the Seine river basin (75,000 km², France) with regionalized projections of precipitation and temperature (BCCORDEX; Jacob et al., 2012) and using 4 GCM, a total of 5 RCM, and 2 prospective situations for the timeline 2100 (the most extreme IPCC scenario 8.5 and the stabilization RCP 4.5). Both hydrological and biogeochemical simulations are now running for all the river basins contributing to North East Atlantic façade.

In the meantime, development of the estuarine model has already started. Steady state simulations performed for different hydrological conditions characteristic of the Seine estuary already allowed calibrating C-GEM's hydrological module for this system and its biogeochemical module, which relies on a generic parametrization for temperate estuaries (Volta et al., 2016). Further validation of the modeling approach will then be carried on three other well monitored French estuaries (Loire, Gironde and Charente) for which large and diverse datasets are available and preliminary hydrological set-ups have already been designed. Once the robustness of the hydrological and biogeochemical modules of C-GEM will have been tested, an application to ~30 rivers, which account for > 90% of the French water discharge to the north-east European Atlantic shelf (Figure 2).

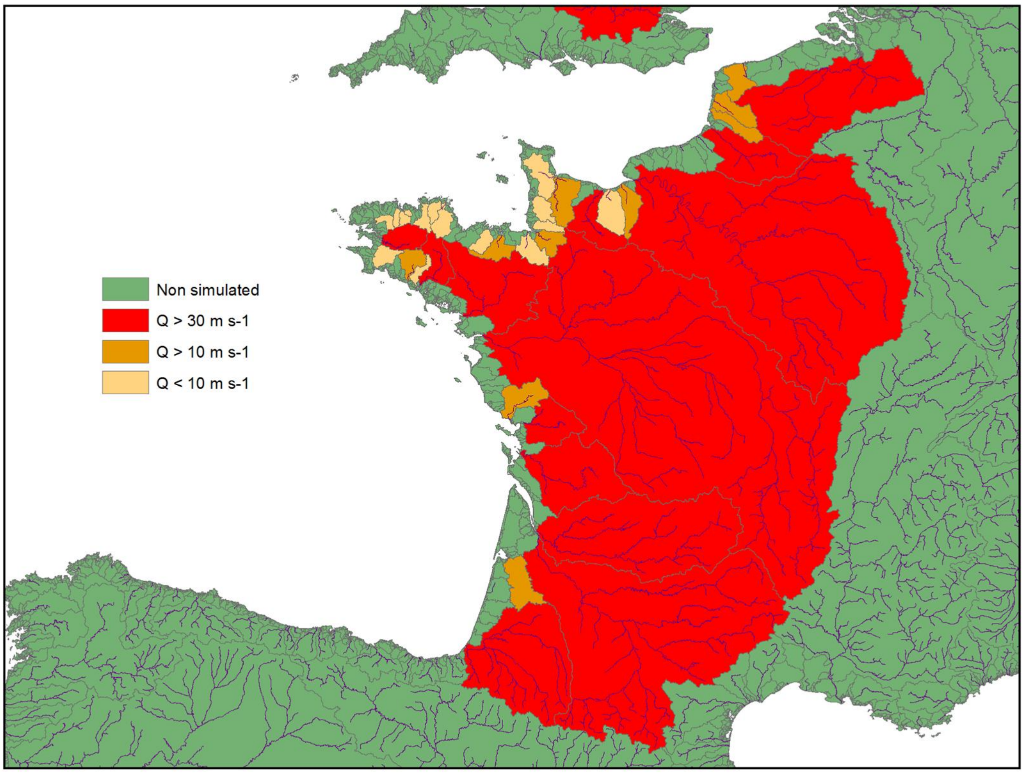


Figure 2: Watersheds flowing into the north-east European Atlantic shelf. The watersheds colored in red and orange will be explicitly simulated with entire C-GEM-pyNuts-Riverstrahler modeling suite.

Upstream, daily boundary conditions for C-GEM will be provided by the outputs of pyNuts-Riverstrahler while downstream boundary conditions will be constrained by a regional hydro/biogeochemical model of the western European shelf (ECOMARS, Ifremer). This unique set-up, will allow performing the first ever fully transient simulations of the estuarine filter at the regional scale. The ability perform such simulations over an entire will allow capturing the complex seasonal dynamics of carbon and nutrients through the estuarine filter and disentangle the main drivers of the biogeochemical processing of terrigenous material delivered by rivers in such systems. Model outputs will include spatially and temporally explicit regional estimates of nutrient processing and retention as well CO_2 exchange along the Western Europe estuarine filter.

Deliverables for 2017-2019

Sub-project 1:

Deliverables	Type	Time of delivery
A comprehensive process-based classification of climate models	Paper	December 2016
Archive of multi-sectoral impacts indicators	Database	June 2017
Time of emergence of impacts on agriculture	Paper	December 2017
Time of emergence of multisectoral impacts	Paper	September 2018

Sub-project 2:

Deliverables	Type	Time of delivery
First phase of inter-comparison	Paper	February 2017
Interfrost workshop	Workshop	November 2017
Archive of CY meteorological and soil temperature Syrdakh field dataset	Database	End 2017, after compilation of September field survey
Simulation of talik evolution with Cast3M and comparison with Syrdakh field data	Paper	Mid 2018
Time of emergence of impacts and simulation of future impact of CC on river-valley system	Paper	End 2018

Sub-project 3:

Deliverables	Type	Time of delivery *
A new integrated quantitative assessment of nutrient and carbon transfer in western in western EU-rivers-estuaries	Paper	December 2018
Map of inland and estuarine aquatic ecosystem alterations under climate change (in river basins from the Rhine to the Guadalquivir)	Dataset	May 2018
Past and contemporary and future (climate-impacted) water, carbon and nutrient (N, P, Si) fluxes deliver to western EU coastal seas (southern bight of North sea, English channel, Gulf of Biscay, Iberian shelf)	Dataset	December 2018
Regional GHG estimate from regional aquatic system (rivers + estuaries) in western EU – contribution to global budget estimates	Paper	December 2018
Direction and magnitude of changes driven by climate, along the aquatic continuum of the North-East Atlantic domain (including time of emergence of impacts)	Paper	June 2019
CO_2 exchanges with the atmosphere,	Dataset	June 2019

2.3.4 Model development (TWP1)

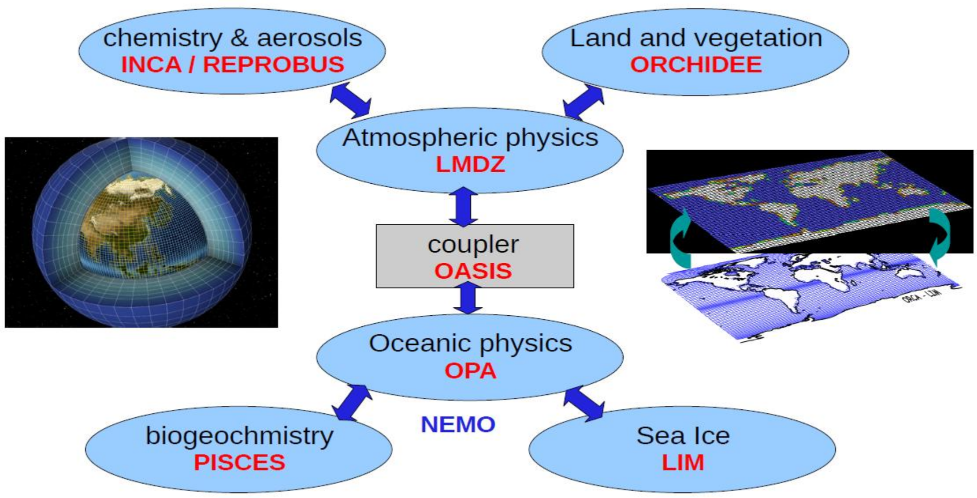
Project lead: Jean-Louis Dufresne, Olivier Boucher

Participants

Tasks	L-IPSL contributors	External collaborators
High resolution ocean modelling	Julie Deshaye (LOCEAN) Olivier Aumont (LOCEAN) Laurent Bopp (LSCE) Christian Ethé (IPSL)	
Running and checking a suite of CMIP6 simulations	Olivier Boucher (IPSL) Sébastien Denvil (IPSL) Marie-Alice Foujols (IPSL) and the IPSL-CMC steering committee	
Running and processing data for high resolution simulations	Olivier Boucher (IPSL) Sébastien Denvil (IPSL) Marie-Alice Foujols (IPSL) Thomas Dubos (LMD) and the IPSL-CMC steering committee	

Project summary

IPSL is continuously developing IPSL-CM, its Earth System Model, since about twenty years. This model is central to many research activities from theoretical studies to analysis of observations, from paleoclimate to future climate changes, from very specific studies to contribution to large coordinated experiments like CMIP. Currently, about 100 persons use and develop this model, and a much larger number of persons use the model results, within the IPSL community and beyond.



The IPSL-CM model is composed of physical, chemical and biochemical models of the various compartments (atmosphere, ocean, land, cryosphere) of the climate system. These models are all developed by IPSL generally in connection with other institutes. They are coupled with the OASIS coupler developed at Cerfacs as sketched in the figure above. Two new versions of this model, IPSLCM6.1 and IPSLCM6.2, are in development and will become operational for CMIP6 in 2018. A next generation version that will use the new DYNAMICO dynamical core for the atmosphere is in development for a use in 2019. These developments are supported by different national or European projects, and the support of Labex L-IPSL can make the difference by supporting the following actions:

- *Development of a high resolution version of IPSL-CM.* High-resolution atmosphere models produce an improved precipitation distribution arising from higher-resolution orography and more realistic tropical cyclone frequency. Similarly, the sea surface temperature (SST) and ocean surface fields are better simulated by partly resolving oceanic eddies. It is therefore expected that higher-resolution coupled models will better represent some aspects of the climate at global and regional scales. Until now, IPSL-CM models have been mainly used for simulations over long periods (paleoclimate) or for process studies (cloud feedback, climate-carbon feedbacks, etc.) for which low or medium resolution models were more convenient. We will now also develop and use higher resolution version of our model to better address some topics such as climate change at regional scale. This requires some adjustments in current models as well as the use of the DYNAMICO dynamical core for the atmosphere.

- *Contribution to CMIP6.* The coupled model intercomparison project (CMIP) is central in climate and climate change studies. More than 25 projects have been endorsed for the sixth phase of the CMIP project, and each of them requires a significant number of experiments (typically 5 to 20). As a consequence of the broad range of scientific interest in the IPSL community and the added value of analysing an ensemble of experiments with the very same model, there is a strong interest in running a large ensemble of experiments with the IPSL-CM model. In addition to that, the CMIP results are used by a continuous growing community who request more model outputs and diagnostics. This leads to a complex management of model outputs, a production of a large number and volume of data and a difficult and demanding work to check and publish these data.

- *Development of specific and key aspects of models.* Models need to be continuously developed to improve their characteristics and to allow new possibilities. Many developments are supported by dedicated projects but some are not although they have large impact on model performance. We are in the final phase of gathering all these developments with IPSL-CM6, the new version of the IPSL earth system model. The completion of this work and the evaluation of the model performances will allow us to define in one year our priorities.

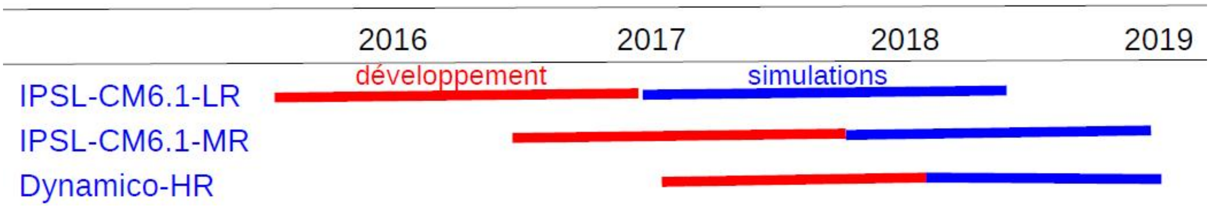
In the next year, our work will be very much oriented by our contribution to the sixth phase of the CMIP project. We have obtained a large amount of computer time and storage volume during the period 2016-2018 that will allow us to have an ambition contribution to CMIP6. We plan to contribute to this project with the following model versions and resolutions:

1. two resolutions for the coupled model:

   - LR : Atm: 2.5x1.5° (144x144) L79, Oce: 1° L75
   - MR : Atm: 1.3x0.6° (280x280) L79, Oce: 1° L75

2. a high resolution (0.5°) atmospheric model with the new dynamical core and the same physical package as IPSL-CM6. We plan to contribute to the prescribed SST experiments of the HighResMIP project with this model in late 2018.

The calendar of model development and simulations is the following:



The development of IPSL-CM6.1-LR is almost finished and this model version will be frozen late 2017 / beginning 2018. Test and improvements to prepare higher resolution version of the model have started and has benefit of some support to help the development of the high resolution version of the ocean model (task 1). IPSL will contribute to CMIP6 with a very large number of experiments and simulations, and support to help performing these runs is also asked (tasks 2 and 3).

Progress so far

Task 1: Preparation of model configurations for CMIP6
Person hired: Thibaut Lurton [March 2017-now]

There has been a tremendous effort to prepare the IPSL-CM6 model configurations for CMIP6. It is out of scope to describe it all here, and we focus mostly instead on the work performed by the person hired on L-IPSL funding.

Algorithm for mass-conserving interpolation of aerosol emissions

The method for interpolating aerosol emissions in the INCA aerosol model has been improved in order to prescribe a continuous time evolution of emissions that conserves the individual monthly means. The CMIP6 protocol provides monthly mean values. We have used the algorithm pulished by Sheng and Zwiers (1998) to correct the monthly mean values so that the monthly means are conserved after the linear interpolation in time which is performed online in the model. As the method may introduce negative values, we have introduced the sophistication of Taylor (2000) so that emissions are prescribed to 0 during such months. This has implied to iteratively modify the monthly mean values and adapt the time interpolation according to the presence or absence of such zero emissions values (see Fig. 1).

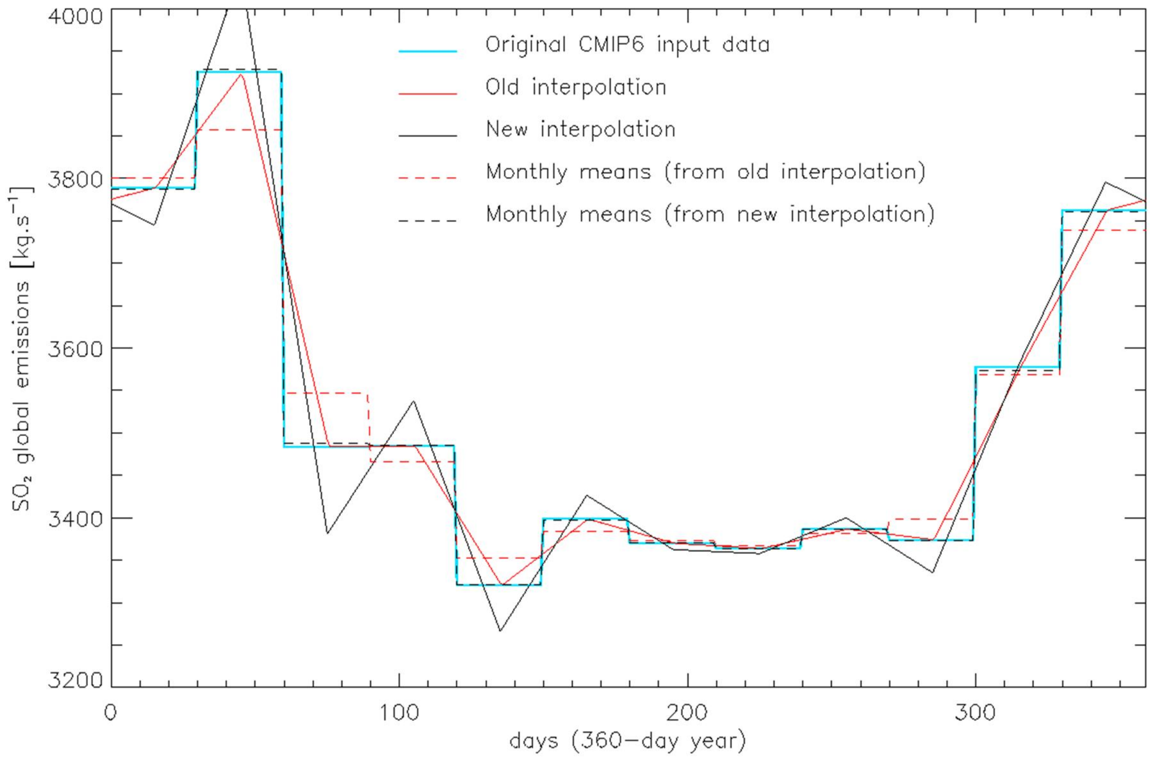


Figure: SO_2 monthly emissions (light blue curve), linearly interpolated between months (red curves), mass-conserving linearly interpolated between months (black curve). Corresponding means in dashed curves.

References

Sheng, J., & Zwiers, F. (1998). An improved scheme for time-dependent boundary conditions in atmospheric general circulation models. *Climate Dynamics*, *14*(7), 609-613.

Taylor, K. E., Williamson, D., & Zwiers, F. (2000). The sea surface temperature and sea-ice concentration boundary conditions for AMIP-II simulations. *Program for Climate Diagnosis and Intercomparison*. Lawrence Livermore National Laboratory, University of California.

Final preparation of the CMIP6 forcings

Most CMIP6 forcings have been verified and qualified for CMIP6. We have checked and documented the consistency of all forcing terms implemented in IPSL-CM6 with the original datasets: tropospheric aerosols, volcanic (stratospheric) aerosols, solar constant and its spectral variations, tropospheric and stratospheric ozone.

The ozone profiles have been interpolated in the LMDz model in a way that matches of the tropopause level of the CMIP6 dataset with the local tropopause of the LMDz model. This is a substantial improvement over the CMIP5 protocol.

Azerosol climatologies have been generated for the 1850-2014 period using INCA and a configuration of LMDZ that is as close as possible to that of the final IPSL-CM6 configuration. Oxidant levels were prescribed from previous CMIP5 simulations and interpolated to individual years from the decadal dataset. To speed up the generation of the climatologies, the historical period was divided into five chunks with a sufficient spin up for each. A three-year running mean is then applied on the monthly climatological means to smooth out the interannual variability due to emissions.

Pseudo-historical simulation

A preliminary historical simulation was performed to anticipate any problem with the historical CMIP6 forcings (and preliminary aerosol climatologies interpolated between pre-industrial (1850) and present-day (1995) climatologies by scaling to global SO_2 emissions). The simulations have helped identified a number of shortcomings. The evolutions of the global mean 2-meter and sea surface temperatures are reproduced below and have validated our approach to perform a model tuning on a present-day control rather than a pre-industrial control simulation.

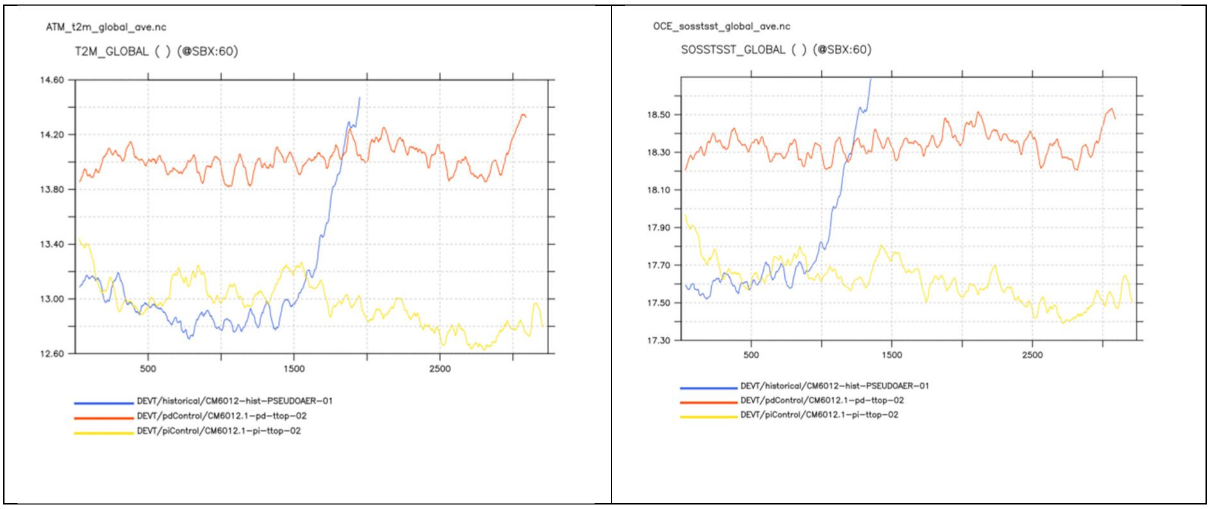


Figure: Global mean two-meter temperature (left) and SST (right) for the present-day control (red curve), pre-industrial control (yellow curve) and the pseudo-historical simulation (blue curve).

Meanwhile Thibaut Lurton has also taken responsibility for the IPSL contribution to ES-DOC.

Task 2: Development of a high resolution version of IPSL-CM

In order to take into account the effect of processes that are smaller than the model grid, atmospheric and oceanic models have parameterizations. When changing the grid resolution from a few hundreds to a few tens of km, most parametrizations can be kept unchanged but some have to be adapted. In the atmosphere, a classical problem when increasing the resolution is the tendency of model to develop so-called grid point storms, i.e. strong numerical convective rainfall associated with a strong vertical ascending motion in one particular column of the model. Developments to solve this problem are ongoing within an existing project (ANR Convergence). For the ocean, a high resolution NEMO 1/4° model (1442x1021x46 grid) will be used. A direct consequence of a better resolution is the improvement of the interactions between currents and topography. A better resolution allows an improvement of meso-scale processes provided that parameterizations are modified. Indeed, this spatial resolution is not sufficient to simulate the meso-scale processes in the low latitudes that cover more than 50% of the ocean. Without these improvements, the current simulations show very noisy vertical velocities, which is unsuitable for the biochemistry processes which variables are primarily driven by the vertical dynamical processes.

The developments made within the Drakkar collaboration that originally developed the high resolution NEMO 1/4 ° model, ORCA025, have been included in standard version of NEMO used by the IPSL climate model, eORCA025. Compared to ORCA025, the geographical imprint of eORCA025 has been extended to the south so as to represent better the coastline of Antarctica and the freshwater fluxes from the continental ice shelf toward the ocean. More precisely, these fluxes have been split in two components: freshwater fluxes along the coastline to mimic the dynamics of under-ice shelf seas (currently parameterized, but the configuration is ready to sustain an explicit representation of those dynamics) and freshwater fluxes associated to iceberg melting in the open ocean. The latter has been shown to reduce significantly an overestimated polynya in the Weddell Sea. Apart in the southernmost part of the configuration, the bathymetry of eORCA025 is identical from that of ORCA025 which has been carefully tuned so as to represent as well as possible current-topography interactions, in particular in small straights or deep ocean canyons (such as Faroe-Bank Channel).

At all latitudes, simulations with eORCA025 show intensified the eddy kinetic energy (EKE) at surface when compared to coarser resolution simulations, suggesting that they resolve more small scale processes, as expected. However, at this resolution, the mesoscale ocean processes are hardly resolved in the tropics only. Elsewhere, the model outputs are likely to reflect both numerical noise and realistic ocean processes. Gildas Mainsant delivered a substantial effort to reduce the numerical noise of eORCA025 simulations by adjusting the choices of model schemes and parameters. This task involved running multiple tests of sensitivity over interannual simulations and then intercomparing those, which is quite challenging at such high resolution on the global scale. It has led us to tune the horizontal viscosity, the conductivity of snow, the horizontal advection and convection schemes, the vertical mixing representation and the sub-meso-scale parameterisation, compared to the original ORCA025 configuration. Still ongoing is sensitivity experiments to mesoscale parameterisations which require ad-hoc tuning so as to preserve mesoscale processes where explicitly resolved by the model.

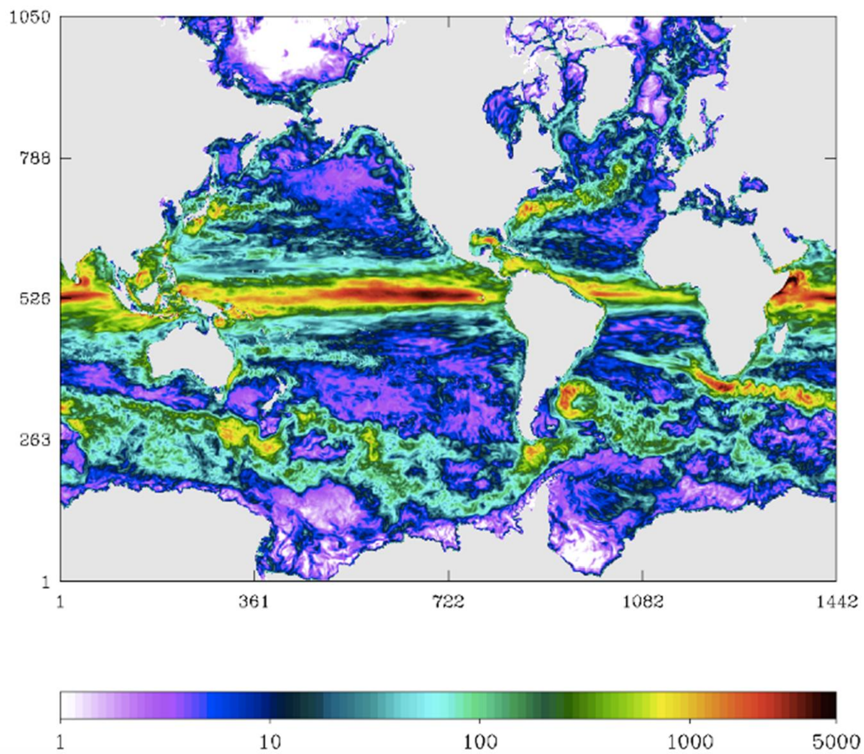


Figure: Eddy kinetic energy for year 1999 (run started in 1981 from climatology and rest, and uses CORE2 atmospheric forcings) in the model grid framework (colors follow log scale, unit is cm^2/s^2) for a simulation with the eORCA025 model.

In 2017 work has focused on a high resolution (280x280xL79) configuration of the LMZ model. This version has also been coupled with the NEMO 1° configuration and a 1à-year simulation could be performed and is being analysed.

Program until 2019

Task 2: Help to run and check a suite of CMIP6 simulations
The sixth phase of the CMIP project is very ambitious. The broad and diverse interests of IPSL scientists, the features of IPSL-CM6 and the computer resources we have obtained for the next years open the possibility of a major contribution of IPSL to CMIP6. IPSL scientists lead or are currently strongly involved in twenty MIPs endorsed by CMIP6. This will require to run a large ensemble of experiments and to publish the data produced. More precisely, this will require to drive the very large number of output variables (about one thousand), to specify the precise configuration of the model and the forcings, to check the proper execution of hundreds of runs, and to check the quality of the outputs and to publish them. We ask for a one year software engineer to help on these two latter tasks.

Task 3: Help to run the High resolution version of the IPSL-CM6 model
We plan to finish the developments on the high resolution of the IPSL climate model at the end of 2017 and the development of the high resolution atmospheric model with the new dynamical core by mid-2018. The runs and the processing of the data are very demanding and we ask for a one year software engineer to help doing these tasks.

Deliverables for 2016-2019

Task 1*:* A first version of the high resolution version of the ocean model, eORCA025

Task 2: A suite of CMIP6 runs are performed and their results are made available to the community through ESGF.

Task 3: An ensemble of runs with the high-resolution version of the IPSL model are performed and their results are made available to the community through ESGF

Budget for 2016-2019

Expenses already decided in the 2015 plan

Post-doc for ocean modeling (starting early 2016): 65 k€ - Spent
This amount represents 55 keuros/years for salary + maximum of 10 keuros/year including computer and other computing facilities, participation to 1 national and 1 international conference every year, 1 publication/year

Software engineer for running and checking CMIP6 simulations (from March 2017): 60 k€ - ongoing
This amount represent 55 keuros/years for salary + maximum of 5 keuros/year including computer and other computing facilities, participation to national and international meetings

New proposed expenses

Software engineer for running and processing data CMIP6 simulations (2018): 60 k€ - **continued**

This amount represent 55 keuros/years for salary + maximum of 5 keuros/year including computer and other computing facilities, participation to national and international meetings

Total for 2016 - 2019: 185 000 €

2.4 Invitation of scientists

During its initial phase, the L-IPSL Labex has funded short durations stays for international scientist to initiate or promote collaborative research with the French laboratories involved the LABEX (LATMOS, LISA, LMD, LOCEAN, LSCE, METIS). For the long-term Action Plan, the Research Committee has decided to maintain this call with a specific orientation toward senior scientists bringing a complementary expertise to the IPSL scientists. The topics considered as relevant for this call as larger than the one defined for the "Large Projects" but correspond to the main the scientific questions initially defined by the L-IPSL:

- Factors controlling the atmospheric composition
- The predictable part of climate evolution for the next decades considering anthropogenically induced changes and natural fluctuations
- The regional climate implications of global warming
- The expected impacts of climate change on natural resources and environmental changes
- The risks of abrupt unpredictable climate evolutions
- Numerical modelling of the climate system
- Strategy for observational studies: instrumentation, analyses, dissemination
- Assessment of uncertainty in climate diagnostics and projections

The call for Invited Scientist open in October 2015 allowed to found 3 proposals among the 6 submitted. The call has been re-conducted in 2017 with a strong increase in the number of submissions. Regarding the quality of the submitted proposals, the committee has decided to fund 6 proposals among the 12 submitted (see table below). Compared to the "Large Projects", this call allows to support fundamental or process studies that are useful to reach the general objectives of the Labex. A final report have been asked to the successful invited scientist that are given as annex when available.

Inviting Laboratories	Invited Scientist	Status	Duration	Topic
			2015 Call	
LATMOS, LMD	E. Girard	Professeur UQAM, Quebec, Canada	3 months	Impact of biomass burning aerosols on clouds and on the radiative budget.
LOCEAN, LMD	M. P. Lelong	Senior Scientist, NorthWest, USA	2 months	Representation of near-inertial waves and their interactions with eddies In the ocean model NEMO MED36"
LSCE	H. Rensse	Professor, VU university, Amsterdam, Netherland	1 month	Application of a Data Assimilation method for water isotope data to study key climatic shifts during the LGIT.
			2017 Call	
LISA, LOCEAN	G. Okin	Professor, UCLA, Los Angeles, USA	1 month	Interaction between vegetation, land use and mineral dust emissions in the Sahel
LMD, LATMOS	A. Tompkins	Scientist, ICTP, Trieste, Iltaly	2 months	Investigation of the physical mechanisms driving convective organization in the tropical atmosphere with convection-permitting models
LMD, LATMOS	J. Galewski	Professor, U. New Mexico, USA	3 months	Constraining the simulation of the water vapor cycle with water isotopic compositions derived from IASI/MetOp.
LATMOS, LSCE	P.E. Kirstetter	Adjunct Faculty, U Oklohoma, USA	3 months	Analyzing the environmental water vapor conditions associated with cloud types in the tropical atmosphere based on multivariate space-borne observations.
LOCEAN, LSCE	A. Winter	Professor, Indiana State University, USA	3 months	Reconstruction of quaternary climate using tropical Atlantic proxies (sclerosponges, speleothems, corals).
METIS, LMD	M-H. Lo	Assistant Professor, National Taiwan University, Taiwan	1 month	Assessing the groundwater storage changes in the future warming climate

2.5 Budget Summary for research 2016-2019 (expenses starting in 2016)

Project	Period	Description	Amount (Keuro)
Large Project 1	2016 – 2017	Post-doc for data synthesis	110
	2018	Extension for 1 year	50,5
	2016 – 2017	Post-doc for Modeling	110
	2018	Extension for 1 year	50,5
	2016 – 2017	Workshops / Invitations	4
	2016 – 2017	M2 internships	8
		Total Large Project 1	**333**
Large Project 2	2016 – 2017	Post-doc Volcanic forcing	55
	2016 – 2017	Post-doc Solar forcing	110
	2017 – 2019	Post-doc coupled Reconstruction	110
	2017 – 2019	Post-doc variability at local scale	110
	2017-2019	Post-doc atmospheric reconstructions	110
	2017-2018	Post-doc variability at regional scale	72
	2017-2019	Computers, travel, publication	27,5
		Total Large Project 2	**594,5**
Large Project 3	2016 – 2017	Post-Doc sub-project 1 Agriculture	110
	2016 – 2017	Publications & Conferences	4,5
	2016	Workshop sub-project 2	7
	2017-2018	Post-Doc sub-project 2	103
	2017-2018	Travel, Siberia field campaign, public.	16,5
	2017-2018	Post-Doc sub-project 3	110
	2017-2018	Publications	3
	2017-2018	Travel	1,5
		Total Large Project 3	**355,5**
Model Development	2016-2017	Software Engineer	55
	2016-2017	Post-doc Ocean Modeling	55
	2017-2018	Software engineer	55
		Computing & conferences	20
		Total Model Development	**185**
Foreign Scientists	2016-2017	3 visits for 2016-2017	**30**
Foreign Scientists	2017-2018	8 visits for 2017-2018	**30+50=80**
Foreign Scientists	2018-2019	3 visits for 2018-2019	**30**
Total		*Total*	**1608**

Table of expenses for the long-term phase of the LABEX. Numbers in black indicate expenses that were budgeted in the 2016 Action Plan. Red indicates total new expenses including additional decided in this plan.

2.6 Publications (from the start of LABEX)

The list below only mentions published articles referring directly to the LABEX grant. Sources Web of Science, Google Scholar.

1. Ait-Mesbah, S., Dufresne, J.L., Cheruy, F., and Hourdin, F. (2015). The role of thermal inertia in the representation of mean and diurnal range of surface temperature in semiarid and arid regions. GEOPHYSICAL RESEARCH LETTERS *42*, 7572–7580.
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13. Cheruy F, Dufresne JL, Hourdin F, Ducharne A. Role of clouds and land-atmosphere coupling in systematic mid-latitude summer warm biases and climate change amplification in CMIP5 simulations, GRL41, 6493–6500, doi:10.1002/2014GL061145
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3. Innovation and expertise transfer

Climate research teams – in particular IPSL – have built scientific knowledge and technical tools that is transferable beyond the sole realm of research. A stronger and more integrated link between climate science and society is therefore required to build this transfer. This will steer employment for students, further use of IPSL science in many domains, and new scientific questions, sometimes fundamental from downstream applications.

In 2017 and for 2018, the L-IPSL transfer capacity has focused on "climate services" actions: climate information transfer for adaptation. It pursues the strategy elaborated in 2013, which proposed a few actions that could be developed in a time frame of a few years by the LABEX teams, building upon existing activities.

The goal for IPSL is to develop an interface between the research and the many applications and services that could be developed with targeted communities. The L-IPSL must therefore develop active links with its network of companies, and have a capacity to:

• Provide projection and processed data (eg, general indicators on all climate projection data, CMIP5, all CORDEX areas), consistent with the work done within the framework of IS-ENES and CLIP-C FP7 Copernicus projects

• Provide software prototypes developed in IPSL laboratories (eg statistical analysis of series, bias correction of datasets from the current climate and downscaling)

• Develop “pilot studies " with industry and SMEs, but with an innovative character, ie non-repetitive, and that would have a return on scientific research (new original questions, ...)

Several actions have been undertaken, and a number of actions are underway, also funded through external calls (Climate KiC FP7/H2020 projects, MEDDE, Copernicus). The dynamism of the area of climate services has also led to start new unforeseen actions. So far funding of activities has been primarily external to LABEX, but LABEX has funded and achieved several key steps, which are summarized here.

3.1. Climate Services and Expertise web site

A web site, http://cse.ipsl.fr has been set up in order to disseminate information and climate-service projects developed at IPSL. This was the first attempt to collect all the in-house information on climate information development. It turned out that a number of projects were developed with stakeholders, which needed to be highlighted in the context of climate service developments. The web site also includes access to news, data sets.

3.2. The PRODIGUER service and the development of ESGF

The PRODIGUER service is at the cornerstone of the data distribution activity, both for research and climate services. The LABEX has supported the development of the PRODIGUER data distribution service, and expanded its activities. The service core mission is to develop facility providing climate projections at global or regional scale relying on major international exercises such as CMIP or CORDEX, as a node of the international distribution network (ESGF). The second core mission of the PRODIGUER team is to lower the barrier towards the accessibility of the ESGF resources.

3.3. In-house processed climate projections algorithm development

A new step has been achieved in production of bias corrected (or bias adjusted datasets), as a necessary step for the development of impact studies and climate services. A new algorithm for precipitation has been tested for precipitation (Vrac et al., 2016, J. Geophys. Res.). This algorithm, which is in the family of the Cumulative Distribution Function transform (CDFt) accounts for potential biases in precipitation frequency. It has been developed and applied now in several cases, including the applications below. CDFt has also been adapted to a number of situations and datasets, which required rewriting in FORTRAN to handle large data sets such as EUROCORDEX or CMIP. Typical developments have been carried out in order to handle reference observation-based data sets which have a lower resolution than the climate projection itself, which is the case in most applications of CORDEX-011.

The goal is now to generalize the use of CDFt. The new developments of CDFt have been applied:

- As a first pioneering example over Europe using E-OBS reference data, within the LABEX testing framework, and within the framework of the international bias-corrected cordex effort led by SMHI; data sets are now published on the ESGF server and on the CSE web site;

- To temperature and precipitation variables for DRIAS (the CDFt development stage was not complete at that time, which now necessitates an update);

- As an innovative application to produce a climate projection data set suited to the energy sector, within the CLIM4ENERGY Copernicus C3S demonstrator project http://clim4energy.climate.copernicus.eu ;

- As another innovative application to the ensemble of CMIP data for a few variables, within the framework of the TCDF contract (see SME projects P1 below).

3.4. Provision of bias-corrected data to DRIAS and the National scenarios

One of the early application of CDFt was for the DRIAS national climate service. This action was essentially funded directly through a MEEM contract for the report on climate scenarios for France. For the first time, EUROCORDEX ensembles were used together with the SAFRAN reanalysis to produce a high-resolution projection data set, now available through the DRIAS server. Precipitation and temperature were bias corrected after a projection on the SAFRAN grid. The analysis of the climate projections was made and reported in the National Scenario report (rapport “Jouzel”).

3.5. Pilot studies with SMEs

Three projects for transfer actions IPSL - SMEs were launched and are still underway. A fourth one had to be put on stand-by for administrative issues: these are being resolved and a new call for tender is about to be issued. The MICADO project should then be running in 2018. Summaries for the four are given below. One project on forest carbon budget, initially selected, was finally not started.

3.5.1. TCDF project (ongoing): Generation of bias corrected CMIP5 and CORDEX essential climate variables data set.

With TheClimateDataFactory (Start of the TCDF spin-off)

Objective

The goal of the project is to develop a post-processing chain software to handle statistical post-processing operations on climate model data sets and generate a first data set of bias corrected climate model simulations using documented procedure. It is the opportunity to develop the post-processing chain expertise within the newly created TCDF spin-off, in order to harness a business-to-business service of climate projection data provision. The post-processing chain is based on the SYNDA software that is an advanced ESGF download manager developed by the IPSL PRODIGUER team. The post processing chain also takes advantage of statistical bias correction techniques developed by Mathieu Vrac within the ESTIMR team at IPSL-LSCE. The project was originally planned to last 12 months. It has been extended to the 31th of December 2017 to ensure the complete production of bias corrected products coming from CORDEX and CMIP5.

The SYNDA SDT (Synda Data Transfer) component handles the synchronisation and download of large data files between the *Earth System Grid Federation* climate model data repository on local resources. The SYNDA SDP (Synda Data Processing) component handles a workflow engine - it orchestrates complex distributed interdependent tasks triggered upon download completion (cf. figure). Principal data sets on ESGF are the CMIP5 and CORDEX projects that are a set of global (CMIP) and regional (CORDEX) reference climate simulations under several atmospheric CO2 future conditions (the so called *Representative Concentration Pathways).*

Progress

During the project several computational modules have been developed to perform the calculations as well as to apply quality control procedures both on technical specifications (ESGF file standards) as well as a data check (outliers detection). As of December 2017, development and technical testing of the chain is over, the development phase has been finalized by January 2017. What remains to be done are the last 10% of the so-called “production” phase that is the generation of the data set. TCDF is planning to commercialize those products as soon as possible and has already started to engage with potential interested parties.

Perspectives

The climate data factory (TCDF) is a climate service provider of post-processed climate change model data to the climate change impact and adaptation communities of both scientists and practitioners. Indeed climate change impact studies require data that are becoming difficult to access and need correction from systematic errors in order to be used in impact models. The data management segment of the climate services market was evaluated at 850M euro in 2015.

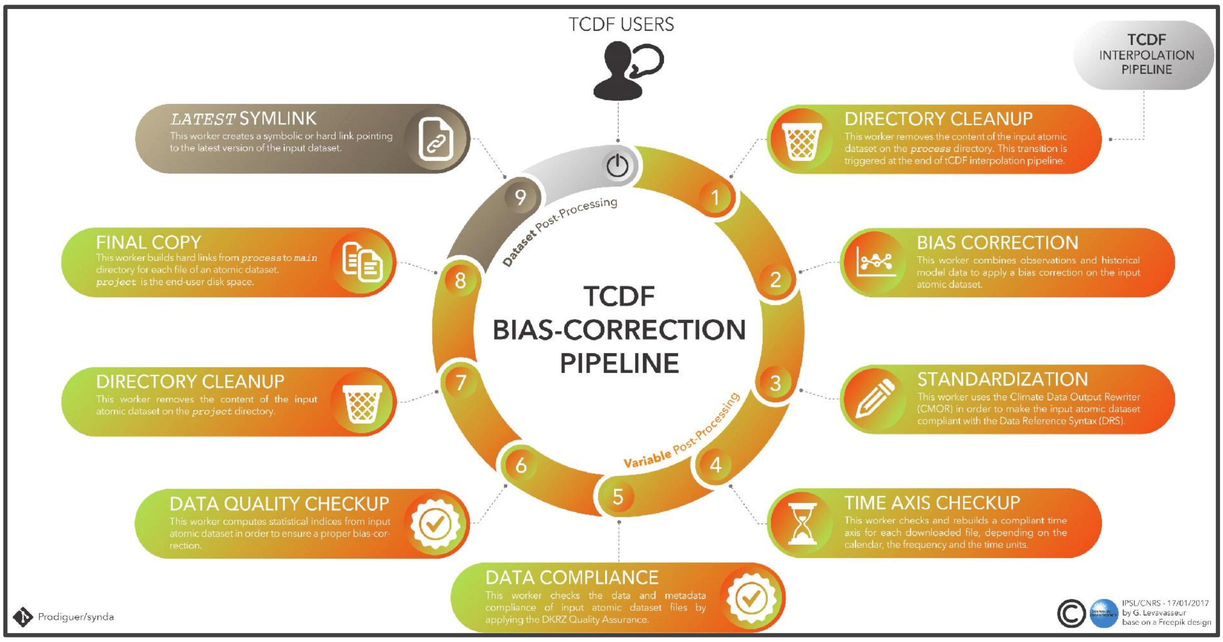

Figure TCDF project: *Inclusion of the bias-correction module in the synda pipeline.*

3.5.2. GTI project (ongoing): A « proof of concept » innovation project on statistical sub seasonal forecasting, using an analogue method.

With ARIA Technologies

Objectives

Stochastic weather generators (SWGEN) have been designed to simulate large ensembles of climate variables that have a realistic spatial and temporal behavior. P. Yiou (PY) designed a SWGEN based on analogues of circulation, to simulate temperature variations at many sites. This SWGEN uses NCEP (National Centers for Environmental Prediction) reanalyses that are updated regularly. PY realized that this tool can be modified into a "predictive" mode, by excluding a search of analogues in the current year. ARIA Technologies expressed an interest in this tool to simulate climate variables like temperature and precipitation. The goal of the GTI project is to evaluate the predictability score of this tool, for different time scales, from a few days to a season. The evaluation work is done by Master's students, under the supervision of PY[1] (LSCE) and C. Déandréis[2] (ARIA).

Progress

The first step was accomplished by Mariette Lamige (ML) in 2015, who modified PY's code into a prediction mode. ML made tests of hindcast prediction for 2001-2015, for temperature in Paris and Toulouse. We used the NCEP reanalysis sea level pressure (SLP) to compute analogues and the ECA&D (European Climate Assessment & Dataset) temperature for both stations. ML focused on the simulated trajectories for temperature, i.e. the day-to-day variations. The algorithm generates ensembles of 100 members of 90 days in just a few minutes. ML found an interesting predictive skill for temperature up to 5 days ahead for the simulations. After 10 days, the simulations tend to converge towards a climatology.

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In 2017, Zhongya Liu (ZL) used prediction skill scores that are used in meteorological prediction to test the stochastic simulations for periods of 5 days to 80 days in advance. ZL tried to predict the average temperature of the next 5, 10, 20, 40 and 80 days in a hindcast mode, for 2001-2017. This approach is slightly different to the one adopted by ML, who looked at the trajectories themselves, rather that their averages. ZL used the Continuous Rank Probability Score (CRPS), with a code in R that was made available in June 2017. The CRPS evaluates the prediction skill and compares is with a reference (here: climatology). We find that the CRPS score is significantly positive at all time scales (from 5 days to 80 days), albeit rather far from 1. Excursions of negative scores happen frequently. ZL did not have the time to investigate the cases around negative scores.

Plans for 2018

The results that have been obtained so far are promising. PY and CD plan to redo the recent experiments performed by ZL and ML in order to write a paper.

As a follow up, a future student (to be hired) will test this model on precipitation, which was the original goal of the project. Several scientific issues appeared since 2015. Adapting the domain on which analogues are computed should be performed, in order to optimize the predictor (SLP or Z500) to the predictand (temperature or precipitation). Testing the predictions against Météo France or ECMWF (European Centre for Medium-Range Weather Forecasts) forecast was done only by visual inspection and should be quantified. Plans to recover MF forecasts for France did not work, due to administrative hurdles. Only data from Paris and Toulouse were used, for practical purposes. The entire ECA&D stations could be used, at least for Western Europe.

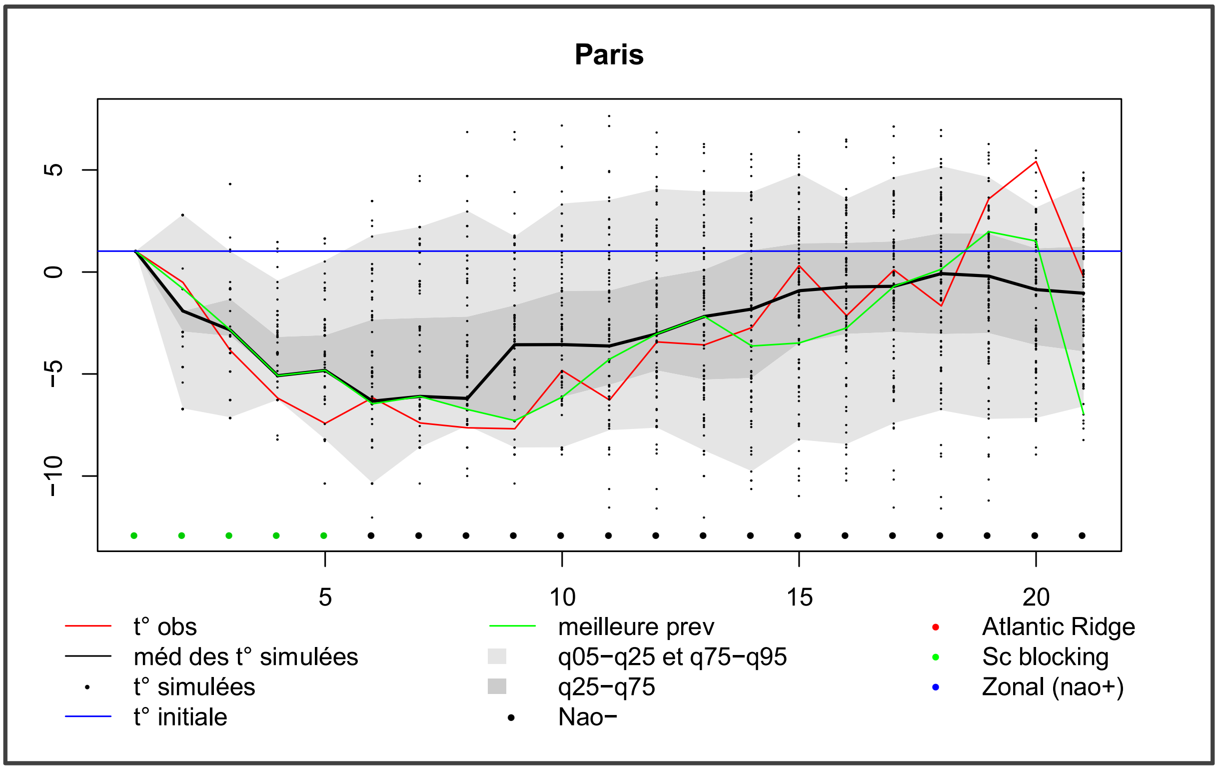

***Figure GTI project**: Temperature hindcast prediction in Paris, initiated 2009 December 11th. Red curve: observations. Black curve: ensemble median.*

3.5.3. ARIPA project (ongoing): Project to develop a platform for adaptation to climate change and phyto-sanitary risks in agriculture.

With ECOCLIMASOL

Objectives
The objective of this project is to offer the agricultural sector an interactive and educational platform to disseminate climate change impact scenarios on crop yields and phytosanitary risks and to construct different adaptation strategies. This interactive tool is based on the web platform ClimaVista, developed by the ECOCLIMASOL company. This platform was developed in collaboration with IPSL for the insurance, re-insurance and agricultural sectors. It is principally commercialized in South America.

Progress
The first part of the developments completed in the ARIPA project has lead to the implementation of two interactive and educational tools. They allow the end-users to explore their practices' influence on their fields' potential yields and on their exposure to phytosanitary risks. These first developments were based on historical climatic data; they can be used to evaluate the influence of the soil water content and of the precipitation regime on yields, and to build adaptation strategies based on the sowing date and the plant variety (shorter or longer growing cycle). The ongoing further developments will allow to translate the climatic change scenarios from the CMIP5 exercise (stocked at IPSL) in terms of yields and phytosanitary risks. The final goal is to enable the end-users to explore their farm's potential and their associated phytosanitary risks.

Plans for 2018
The last developments will be implemented in the interactive plateform. The final tool is destined to be improved according to the users' demands, and to be adapted to new geographical areas - particularly to France and to Europe. To this end, ECOCLIMASOL may in the future collaborate with other companies from the agricultural sector (for instance see companies), from banks or investment funds.

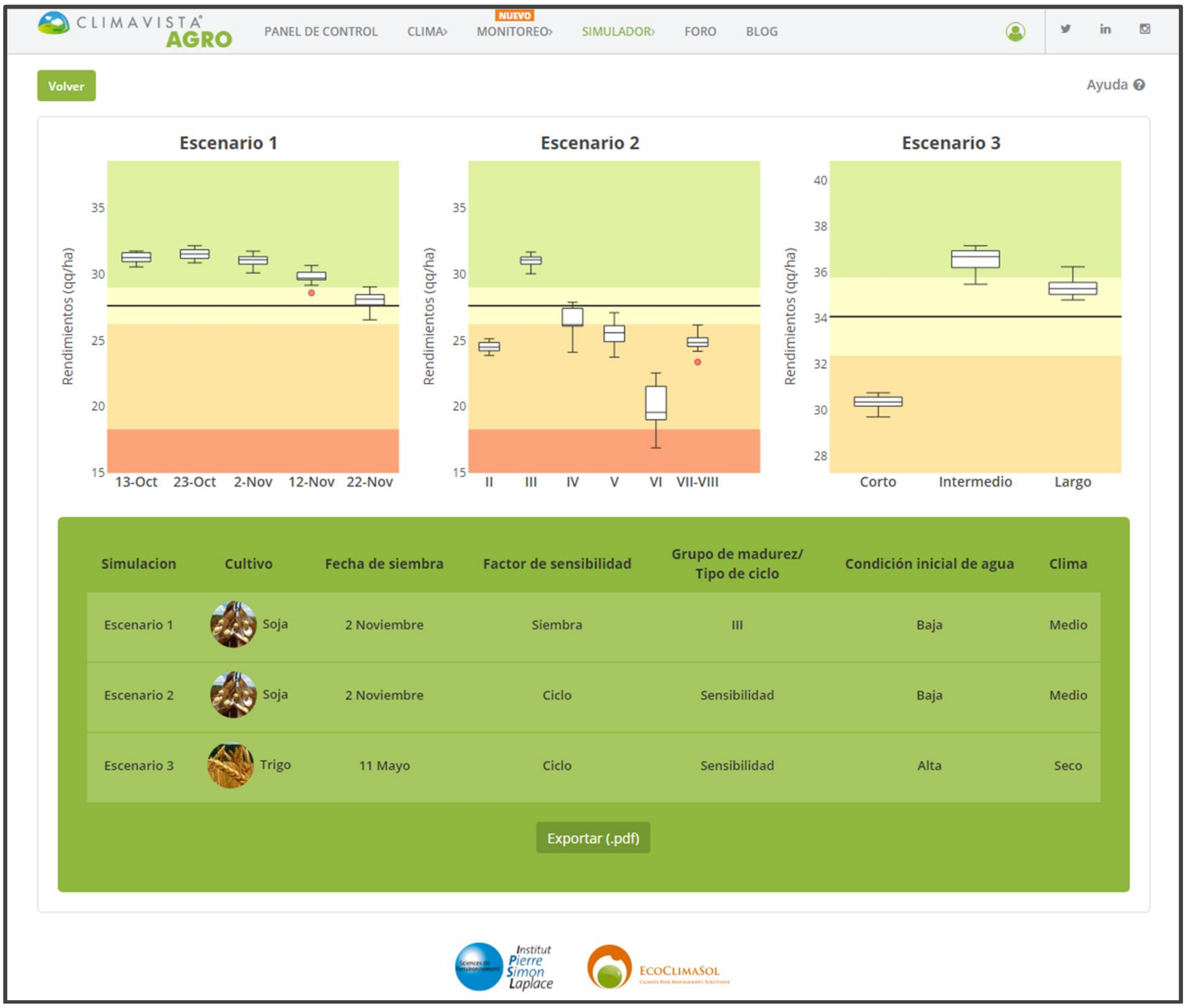

Figure ARIPA project: *Yields comparison for three cropping scenarios. Result of an online simulation.*

3.5.4. MICADO project (stand-by): A project to study the possibility of transfer of the LMDz model to a SME for different climate applications

With ARIA Technologies

Project summary

Down-scaling of climate and climate change simulations is an important aspect in the expertise in climate change impact on society. Comprehensive simulations of the climate modifications arising from a change in atmospheric composition due to human activities can be done only with global models that couple dynamical models of both the ocean and the atmosphere. The length of the simulations (the steady state control climate is reached after a thousand years or more) and their global nature result in the use of rather coarse grids, with a typical grid cell of 100 km or more. This scale is often felt as too large for application to agricultural practices, water resources… Two techniques can be used to downscale those simulations, which present different domains of validity: statistical down-scaling, making direct statistical links between the outputs of the global simulations and local quantities of interest, and dynamical downscaling, based on local simulations performed with models with a finer grid on a smaller area and a shorter period. Those simulations are generally "forced" by the sea surface temperature of the global simulation. The present project aims at assessing the possibility of using for dynamical downscaling a zoomed (with local refinement) version of the global IPSL LMDZ atmospheric model. The use of a global grid with zoom rather than “limited area” grid is more costly, but also present important advantages: the area outside and inside the region of interest are simulated with the same model, avoiding consistency issues which are not enough advertised in this kind of studies. The global model with zoomed grid can be run on the whole planet with a consistent physics. If the zoom is strong, the horizontal winds of the zoomed model can be constraint by the global coupled simulations. Alternatively, a first global simulation can be first performed with the sea surface temperature anomalies of the coupled model. The use of anomalies (difference of the future climate temperature with the present day) allows to correct from important biases in the simulation of the present sea surface temperature that significantly affect the performance of the climate model. The goal of the project is to demonstrate the potential and added value of downscaling with zoomed model using a cascade grids, from global regular grid to a zoom with grid cell of 20 km typically (going farther would require a “non hydrostatic” model). An additional goal is to explore the possible market or clients for such a tool.

Progress

The project first started 3 years ago, then froze due to administrative issues. The initial idea was to apply the tool to a test case which had already been defined in the frame of the ANR project CECIF. It was centered on the French Alps for water resources management. Three problems of different nature were identified at that time: 1/ the test case was not in the main domain of validity of the LMDZ model (very rough mountain and very small scales), 2/ insufficient access to computer resources in the SME and 3/ administrative problems in the contract which resulted in an interruption of the work soon after its beginning.

The SME however hired a permanent position on this topic, and started from the beginning to try to find possible clients for this kind of studies. In particular, it obtained a support from UNDP (United Nations Development Program) to work on water resources in Jordania-Israel-Palestine. Because the L-IPSL project was in stand-by, the study was conducted by the SME with a more classical approach, using the WRF American limited area model. The work suffered however from bad choices in the location of the domain boundaries which probably resulted in erroneous rainfall in the simulations. In the mean time, the SME had to find external solution to run the WRF model on supercomputers.

Plans for 2018

The administrative problems being solved, the project should start again at the beginning of 2018. The NUDP project will be used as a test case in place of SECIF, since : 1/ it is more adapted for the use of LMDZ, 2/ it is a case for which the SME has already conducted simulations for a client. The illustration below shows a first tentative zoomed grid which includes the area of interest with a 20 km resolution. Simulations will be performed with a brand new version of the LMDZ model prepared for the CMIP6 international comparison exercise. This version is frozen since last July and has been used already for hundreds of year of simulations, including a global simulation at 50km resolution. It has been carefully validated also on semi arid area like Sahel.

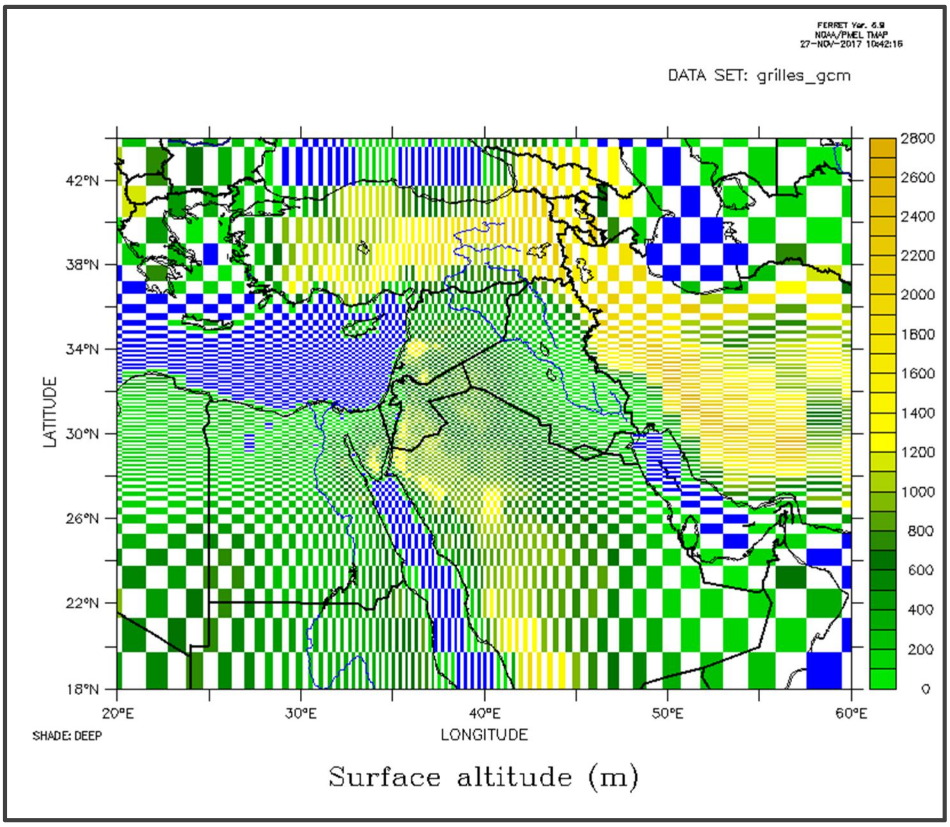

Figure MICADO project*: First tentative zoomed grid which includes the area of interest with a 20 km resolution.*

3.6. Support to the development of the Copernicus C3S programme

Since the start of the climate service program within L-IPSL, the new European Copernicus C3S program has developed and grown. The objective of LABEX was to ease and help the participation of IPSL to this program, by funding travel and stay to researchers to prepare projects.

IPSL is now involved in several C3S funded or submitted projects. The participation is significant in 3 funded projects:

- A sectoral application (CLIM4ENERGY) of climate projections for the energy sector (IPSL leads)
- A core activity (Climate Data Store) on global climate projection data services
- A core activity (Climate Data Store) on developing a roadmap for European climate projections (CRECP), together with the U.K. Met Office
- A core activity to develop the management of the regional climate simulations (CORDEX4CDS, IPSL leads)
- A core activity to complete EURO-CORDEX regional climate simulations (PRINCIPLES)

New tenders could provide new opportunities, in particular in the field of attribution of extreme events, and the continuation of current projects. In addition, IPSL is involved in one ERA4CS project in the field of attribution (EUPHEME).

The LABEX has also supported the development of C3S Copernicus projects at IPSL by hiring a project manager in support of projects developed on the Jussieu site.

3.7. National convention on climate services

A new national-scale climate service development program has recently been proposed in 2017, and IPSL is leading it together with Météo-France, and is now funded (Ministery of Ecology and Solidarity Transition funding). This program has the objective to support the follow-up of a number of initiatives such as DRIAS (national climate service), EXTREMOSCOPE (extreme event attribution), the GICN (assessment of national emission reductions worldwide), and a new portfolio of climate service demonstrators. This is a joint program with Meteo-France, CERFACS, in collaboration with BRGM. The ambition is later to extend the program later to other ALLENVI partners.

Given the contribution of IPSL, results from this developing program will be developed in future action plans. In 2017, the LABEX L-IPSL has supported:

- The funding of a project manager, who is both managing the project and the L-IPSL actions towards the development of climate services. Amélie Rajaud was hired in May 2017 for a 20 month period. The cost was accounted for in the previous action plan.
- A post-doctoral position for 1 year for the development of regional modeling in view of provision of regional simulations

3.8 For 2018 and 2019

The Climate services strategy will pursue its initial phase, with ongoing projects. An update of the strategy will be made in 2018 [this has been delayed by the number of external projects, and the perspective of the EUR IPSL-CGS]. In 2018 all the actions will be revised in the light of the new EUR.

For 2018 and 2019, the LABEX will focus on:

- Finalizing the IPSL-SME program. Funding devoted to these projects appear in previous plans. The total budget for this program is therefore 304 400 euros
- Continue supporting COPERNICUS actions (budget 15000 euros, new proposed budget), and continue supporting the management in particular on the Jussieu site (previous budget)
- Develop the National convention for climate services, by providing in-kind contribution to management, communication, and the funding of the project management

New proposed funding in 2018 (not previously budgetted):

Actions	PA 2017
C3S and ERA4CS support to travel	10000
TOTAL CLIMATE SERVICES	**10000**

4. Education and training

Rationale & general objective

In a very active and complex education and training ecosystem around Paris, the objective of L-IPSL, is to provide bridges between a continuously evolving science, a multi-actor higher-education system (universities, *grandes écoles*, …), and the increasing demand of knowledge from students and various sectors of the society. Our ambition is to contribute to educating a new generation of higher-educated students in climate sciences and to provide training for society relays (teachers, journalists, stakeholders, policy makers), with the general principle to train the trainers.

No Parisian COMUE (groups of nearby universities) alone can address the education and training on such a multidisciplinary science. It is therefore of particular importance, at a time where centrifugal forces apply between institutions and organisms, to bring together all the education and training forces needed to address climate and environmental issues and to use these synergies to improve the knowledge and skills of students, trainers, and society relays about climate sciences. This ambitious objective of L-IPSL on the education and training complements the existing consistency and achievements of climate research in the Paris area (thanks to IPSL federation) and of the associated regional doctoral school.

Organization

The education part of L-IPSL is organized in five axes of work, defined and animated by the education committee of L-IPSL: Improvement of the organization and visibility of the graduate level education on climate sciences in Ile de France (axis 1), Promotion of practical training on climate sciences (axis 2), Development of e-learning (axis 3), Professional training (axis 4), Diffusion of knowledge and communication (axis 5). An education committee has been nominated by the directors of the research units part of the L-IPSL. The education committee includes two professors or assistant professors for each research unit and is animated by a professor nominated by the head of L-IPSL. The committee meets on average every three months to discuss the on-going actions by axis of work, to decide future actions, and to examine funding demands concerning education. The proposals of the education committee are validated by the L-IPSL council (CD L-IPSL). On the top of the actions directly decided and supported by the committee (see below), the procedure to request for funding is bottom-up: any member of L-IPSL can request support for a collective education action by submitting a 1-page description and a budget to any member of the committee. Such a bottom-up method is explained on the WEB site and regularly recalled by emails on the IPSL mailing lists.

Progress status

All the five axes are active and have produced significant results.

Axis1, masters. The improvement of visibility and harmonization of master programs in Ile-de-France has been regularly discussed since the beginning of the Labex with regular meetings of the professors responsible for the different master programs. In a complex and changing environment (creation and evolution of COMUEs and changes imposed by the ministry for master structure and names at national level), visibility of the master's programs has been improved (CLIMPORT website, http://climport.ipsl.fr/) and a first set of joint courses on climate and environment has been running since September 2015 as part of a climate label. The next ambition here is to build a federation of masters with common learning outcomes and more coordinated courses on climate and environment in Ile-de-France, based on the complementary strengths of the different existing masters and IPSL laboratories. This will constitute one key element of the recently accepted project of Ecole Universitaire de Recherche (EUR) IPSL-Climate Graduate School.

Axis 2, Field & lab work. Practical training has been promoted by 1) the development of innovative tools for practical sessions (Jupyter e-python notebook); 2) the identification, development and referencing of few lab sessions and field works; and 3) the design and implementation of a one-week field training for 20-25 undergraduate students on the experimental site of IPSL at Palaiseau (SIRTA), organized with success in 2016 and 2017.

Axis 3, E-learning. The e-learning axis has been very active with the implementation and content enrichment of an open source course management system (CMS) prototype platform to host e-learning contents, previously existing or developed with the support of the Labex (https://claroline.locean-ipsl.upmc.fr/). Numerical resources have been produced and put on this platform for high-school teachers (activities around sea-level rise), for journalists (videos explaining IPCC plots) and for undergraduate and graduate students. L-IPSL is also producing a full ensemble of video ressources for bachelor students (e-calPSuL project) and has supported the development of an online master 2 on climate and medias, dedicated to journalists and communicants and orgaznized jpoçntly with Ecole Supérieure de Journalisme de Lille. (http://formationenligne.esj-lille.fr/).

Axis 4, professional training. Four sessions of professional training have been organized. The main difficulty to overcome for this matter is to adapt IPSL scientific knowledge for professional and business interests. To do so, non-academic relevant topics have been identified, links with CNRS professional training, Climate-KIC and non-academic partners are made, a marketing flyer has been made for our non-academic partners who have attended a joint lunch (in October 2017) to improve the definition of the needs for professional training on climate sciences. This will help the refinement of the training offer and new sessions to be done.

Axis 5, diffusion of knowledge & communication. For knowledge diffusion and communication, the Labex funded a website with questions/answers on climate sciences (http://www.climat-en-questions.fr/) and numerous other communication supports (i.e. paleoclimate textbooks, videos…) or initiatives (i.e. contribution to "Le train du Climat" which evolves towards "les messagers du climat" in 2018-19 with an equipped regional train visiting several cities in France after Marocco end of 2016). It was decided not to organize a thematic school in the first stage of the Labex as many schools already exist. However, L-IPSL contribute to several thematic schools were Labex members were participating or organizing.

Man-power involved

The work in the different axes have been coordinated so far by the members of the education committee who has supervised contractual staff (axis 2, 3, 5), two self-entrepreneurs (axes 1 and 4) and sub-contracting for e-learning platform creation, content developments (graphist, educational engineer) (axis 3). The ambition of the second stage of the Labex (climate label implementation, e-learning content development, new professional sessions, textbooks & summer schools) requires having more man-power for scientific coordination and support to L-IPSL scientists. This is why a scientific assistant has been recruited in 2015 to coordinate and help achieving the different objectives of the education part of L-IPSL. This person is fully operational now.

Short-term objectives

For the upcoming year, we will develop the strategy to move from the Labex activities towards the IPSL-CGS EUR activities. On the Labex side, the on-going actions within each axis will be continued:

- Axis 1: Implementation of applied and professional modules included in the Climate label at master level, evolution of the CLIMPORT WEB platform to account for master changes and start clarify job opportunities inside and outside the academic world.
- Axis 2: Implementation of innovative numerical tools (Jupyter notebooks for lab and field works). 3rd edition of the one-week field training (spring 2018) with improvement of the attraction of undergraduate students (communication plan for this edition include: realisation of a video teaser, reinforced information directly to students)
- Axis 3: Finalisation of the ensemble of videos for bachelor students and of numerical ressources for high-school teachers. Improvement of the diffusion and access to these resources. Start of the realisation of videos to promote the results obtained in the research part of the labex.
- Axis 4: Redefine sessions of training for non-academic partners interested in professional training about climate change, programme and deliver new sessions.
- Axis 5: Continue to support and promote existing summer and winter schools for early-career scientists.

Long-term objectives (last two years of the present labex)

For the third part of the L-IPSL labex, we push further each axis of work and to provide or consolidate integrated education products linking the different axes with each-others but also with the work performed in the research and innovation components of L-IPSL. This general objective is declined into five actions intending to propose a complete offer on education and training for climate and environmental sciences:

1. *Towards a federation of masters in Ile-de-France (axes 1, 2)*
   Beyond the implementation of the climate label, it is of particular importance to organize more clearly and more collectively the master studies about the climate system in Ile-de-France because (not exhaustive): it is a major scientific and societal issue, no university/school can propose a consistent offer alone, the numerous existing M2 seem less attractive for students, and targeted jobs and skills outside of the academic world are not always clear. We propose to coordinate an action to build a federal (regional) master on climate and environment. The main components to implement are a set of common learning outcomes in master 1, master 2 shared courses and notions to provide a minimum common knowledge and skills to all students, specialized courses to be given within each university/school depending on student's project, a set of applied/lab/field courses shared between the different university/school. The technical aspects (mention/pathway names) can be different among participating universities/schools but the objectives and contents can be regionally more shared and clear than today. The development of numerical resources (next section) will help fulfil this objective.

2. *Proposing a path to fully integrate the numerical era (axes 1, 2, 3)*
   Enhancing the actions engaged since 2016, and starting the actions scheduled in the EUR IPSL-CGS, we propose to start the recording of existing courses for those professors and researchers who want to transfer some of their courses as e-learning content. It can be to develop e-learning full programs or just to record supporting online material for on-site courses. The retained solution is both to provide an access to a software allowing individuals to record themselves their own courses, or to organize sessions in specialized centres making online recording of teaching content. The education coordinator will accelerate the advertisement of this offer largely within L-IPSL and organize personal or sub-contracted recordings. The possibility to organize a public event where short presentations of scientific

results are presented and recorded in front of students/colleagues will be studied for the last year of the Labex in its present form (*TedX* model). The EUR IPSL-CGS will provide means to build consistent pathways built upon an ensemble of numerical resources including courses, exercises, case studies and practical work.

3. *Towards an operational platform with e-learning content (1, 2, 3)*
The e-learning prototype platform developed in the first half of the Labex will continue to be fed with links towards or contents of the recorded courses. The different contents will be either freely accessible (open part of the platform) or accessible upon registration as a learner (private part of the platform). This platform will also refer to (or make links towards) the lab and field work contents developed using the Jupyter notebooks. It will also host material for professional training (private part), and scientific learning content based on research and innovation parts of the labex (public part, see point 4). It will also reference the e-calpsul videos produced for bachelor students (see short-term objectives). Finally, a strategy will be decided to move towards a more operational platform when starting the E£UR IPSL-CGS activities.

4. *Promoting research and innovation components of the L-IPSL (1, 4, 5)*
The projects funded by the research and innovation part of the L-IPSL will be turned into educational online material with the help of lead scientists conducting them, using the methodology proposed for action 2. The results will be put on the public area of the e-learning platform. A field work using LIDAR technology will be developed for on-site and e-learning teaching, as an emblematic topic, for different levels of learners from high school students to PhD students. This will make the link between practical work (axis 2), e-learning (axis 3), and instrumental & innovation part of the labex, which supported LIDAR science. A thematic school will be organize at the end of the L-IPSL to present scientific and technological achievements of L-IPSL, with a part dedicated to early-career scientists. A contractual coordinator will probably be recruited to organize this action in 2018.

5. *Supporting the action "the climate messengers" (les messagers du climat, axe 5)*.
During COP21, a train equipped by SNCF with an exposition about climate has made a round trip in France to explain climate change to local population and authorities (http://messagersduclimat.com/). This action implied several scientists from L-IPSL and was a great success. A follow-up is proposed which aims at equipping regional trains with a climate "show" that a lot of persons will see in train stations, including local authorities and teachers, in all French regions. We will provide information material on our educational offer (academic education, professional training, e-learning…) for the public to discover. We plan to support this action with a contribution of 50 k€ in 2017 and in 2018. The train will be deployed in French cities in 2018-19, after having been succesfully visiting Marocco at the end of 2016.

These actions, if successful at the end of the L-IPSL, should lead to a consolidated and complete education and training offer for students, teachers, journalists, non-academic partners, and policy makers in the fields of climate and environmental sciences. They will be integrated smoothly in 2018 and 2019 into the programme of the upcoming EUR IPSL-CGS recently accepted by the ANR.

Budget (2017-2019)

Human resources	***300 k€***
· Education coordinator, CDD, 40 k€/yr	120 k€
· Axis 2 (lab & field work) coordinator, CDD, 40 k€/yr	120 k€
· Training support (axes 3,5), CDD, 18 months, 40 k€/yr	60 k€
Short-term objectives	***60 k€***
· Axis 1 : 2 k€/yr to support the construction of joint master modules	6 k€
· Axis 2 : 10 k€/yr to support the construction of lab & field works	30 k€
· Axis 3 : 3 k€/yr to support e-learning punctual actions	9k€
· Axis 4 : 2 k€/yr to support professional training module development	6 k€
· Axis 5 : 3 k€/yr to support summer and winter schools.	9 k€
Long-term objectives	***257 k€***
· Federal master	12 k€
Meetings, professor « décharge » for organisation & module building, kickoff, …	
· Numerical era	100 k€
Online Content recording in specialized centres for L-IPSL scientists, licences for personal softwares, public event with presentation recording, advertising of the action	
· E-learning platform and content, sub-contracting, 5 k€/yr	20 k€
Management and maintenance of the platform	
· Links with research and innovation	25 k€
Transferring research and innovation results into online educational material (10 k€), final labex symposium including lectures for early-career scientists (20 k€), textbooks development (10 k€)	
· Climate messengers (2x50 k€)	100 k€
Training open call 20 k€/yr	**60 k€**
Total expenses scheduled for the education part for 2017-2019	***677 k€***