L – IPSL LABEX

MID AND LONG-TERM ACTION PLAN
DECEMBER 2016 / JANUARY 2017

This document describes the mid and long-term strategy and objectives of the LABEX program, summarizes past projects and results in current projects. It also describes research, innovation and expertise transfer and education propositions for the mid-term and current achievements. It is an update of the 2015 action plan.

It contains:

- **A summary of the general aims**
- **A summary of main mid-term projects and results (2012-2015)**
- **A presentation of the strategy until 2019 and proposed funding for 2016-2017**
- **Annexes containing more detailed mid-term results**

V5 –
2017/01/09

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1. General aims

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 initial proposal described a general long-term vision of the LABEX but no implementation plan. Along the first few months a methodology to design that plan was discussed. The agenda of the LABEX was then 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 will be 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 the initial vision will be further developed, with implementation of 3 major projects**

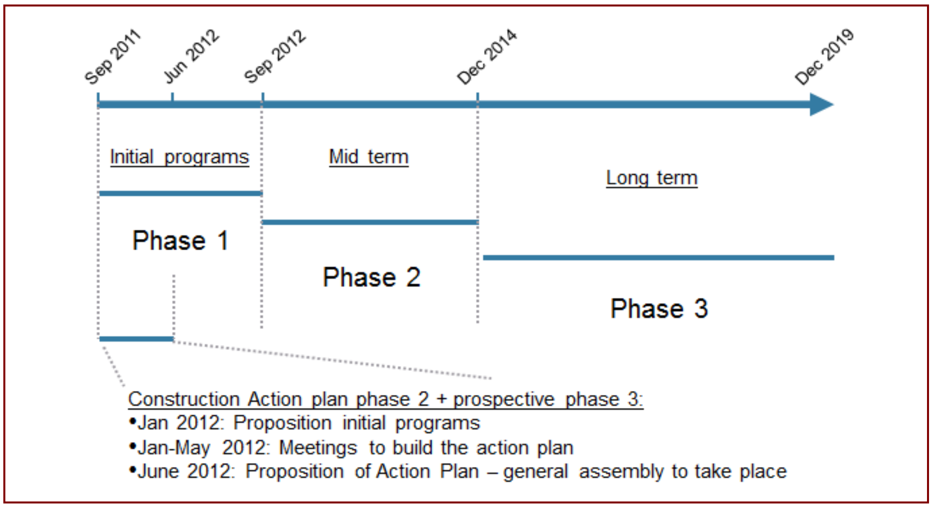


Figure 1: Schematic phases of the LABEX program

For the research program, 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 structures in thematic and methodological work packages that address these questions, and rely on existing IPSL infrastructures (modeling, observing strategies) and will benefit from methodological developments for uncertainty estimation.

The LABEX will also develop an important innovation and expertise transfer program, especially in the domains of innovative instrumentation, modeling and toward the development of climate services.

The LABEX will also bridge training and education with the rapidly developing climate science.

2. Research activities

2.1 Summary of results until end of 2016

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 2016, **71** articles have been published or are accepted so far, among which **9 in Nature and PNAS family journals**. **Fifteen foreign scientists** have been visiting the L-IPSL laboratories through L-IPSL funding on total. **Twenty post-doctoral researchers or engineers** have been hired to conduct the research program, about a half of which coming from a foreign university. **Sixteen** projects have started so far, linked to a 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.

2.1.1 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 projects that were developed in the mid-term phase (some are not finished as post-doc extensions have been proposed). In Annex I, the description of projects and results is given.

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 is extended for a few month beyond end of 2016).

2.1.2 List of funded visits in the mid-term phase

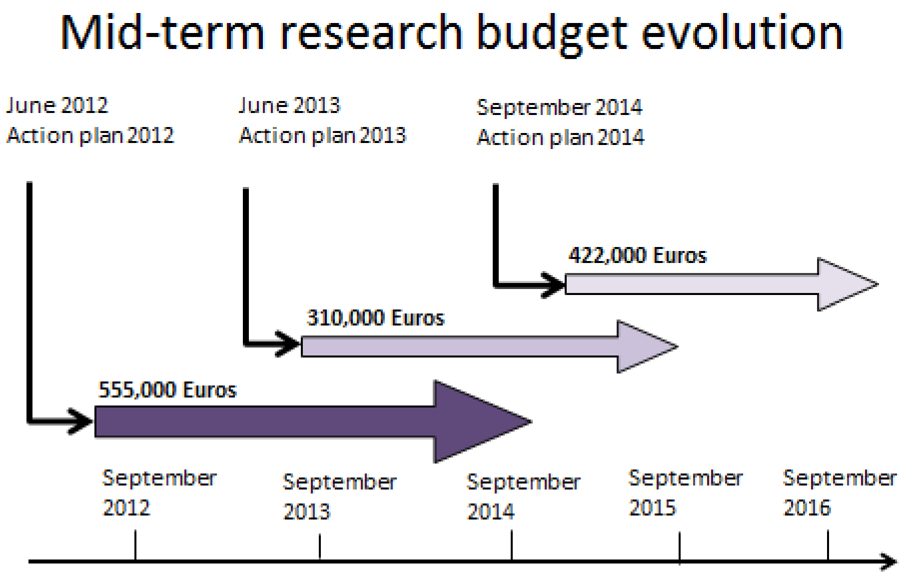
The LABEX also supported the visit of several scientific foreign colleagues during the mid-term phase, with implications in the LABEX work packages. These are summarized in Table2.

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.

2.1.4 Mid-term budget

The LABEX budget is made on a yearly basis with a 2-year perspective (projects decided on Year n can last 2 years). This is illustrated in the figure below.



Each year the budget included 30,000 euros for animation, internal workshops etc… for a 1-Year period, to be decided by WP/TWP leaders

2.2 New 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 now detailed in the following sections, as well as their preliminary results.

Finally, the LABEX wants to keep the possibility to invite foreign scientists. It is scheduled that **two 2-3 month visits per year could be funded and organized**. A first call was issued in 2016 and another call will be launched in 2017.

2.2.1 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

Documenting past climate and environmental changes is essential to increase our knowledge about the Earth System behavior in varied climatic conditions, and to test the climate models which are used for projections. 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 (70000 to 20000 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 data bases for the periods of interest in this project, to improve our models and their capacity to compare their results with data and to perform these comparisons. This will yield a better knowledge or the processes at stake during the last interglacial warm period and the abrupt climatic changes of the last glacial period.

The strategy follows a model-data approach. To do so, we proposed to initiate two actions in parallel over the next 3 years: (1) the data synthesis and (2) the development of model interfaces for tracers representation. These actions should be carried out in parallel to deliver a comprehensive data – model intercomparison, including the spatial variability, over the last interglacial and the abrupt climate variability of the last glacial period. These two actions builds on the previous developments performed within WP5 in L-IPSL: the isotopic paleo-data-base (Tim Bolliet, Bolliet et al., 2015) and the multi-archives dating tool DATICE (Bénédicte Lemieux-Dudon and Lucie Bazin, Lemieux-Dudon et al., 2015).

<u>Axis 1: Data syntheses: Deliverables D1, D2 (+ participation to D4 and D5)</u>

- Compilation and implementation in the L-IPSL paleo data-base of the high to low latitude records with their respective dating constraints for the last interglacial period and the abrupt millennial variability of the last glacial period encompassing H2 and/or H4.

- When needed, adding targeted missing data (sequences of tracers or dating constraints) for key climatic periods or geographic zone.

- Harmonisation of chronologies: synchronization tests in specific geographic zone or by type of tracers using the multi-archive version of DATICE as well as modelling experiments performed using intermediate complexity models (connection with axis 2). We will emphasize the use of non-climatic chronological tie-points.

- Production of coherently dated time series for the investigated intervals.

Since the strategy and tools are the same for the different global data syntheses, one long (2+1 years) post-doctoral position is devoted to the realisation of tasks associated with deliverables 1 and 2. This post-doctoral fellow should strongly interact with the different experts listed in table 1 to ensure their active involvement in the project for selection of the appropriate archives records, additional data acquisition, additional dating constraints on key intervals, dating synchronization tests, … In addition, workshops are set up to review key sequences and dating constraints in the different geographic zones for the production of the syntheses. Finally, the possibility of funding a limited number of M2 internships will permit to fill the gap in key identified sequences of data.

Axis 2 - Model interfaces - Deliverables D3, D4 (+ participation to D5)

- Implementation of an interface based on the BIOME4 model so that the iLOVECLIM and IPSL model output can be compared to pollen data.

- Implementation of an interface for the FORAMCLIM model to be used with both the IPSL and iLOVECLIM model. This will also involve some evolution of the iLOVECLIM marine biogeochemistry model, so that its output can be used as input data for FORAMCLIM.

- Implementation of dust in interactive mode for paleoclimate experiments using the IPSL model.

As for axis 1, the strategy is to fund a 2+1 year post-doctoral position, which gives enough time for the different developments and for their valorisation. Some developments will also be realised by permanent staff of L-IPSL such as the implementation of dust in interactive mode in the IPSL model using outputs from axis 1 (reliable dated synthesis of loess records for a robust estimate of mass accumulation rate associated with dust deposition during the last glacial period).

Axis 3 - Comparison between model outputs and data over selected time periods (D5)

- Application of the modelling tool on LIG and abrupt climate variability of the last glacial period with newly built data bases from Axis 1. These should lead to major publications on these periods.

The exploitation of model simulations and comparison to data synthesis will be performed in the frame of master 2 internships with involvement of permanent staff from labex L-IPSL. This should also be done within dedicated workshops or invitations of external experts

Progress so far

The project started in the course
Axes 1 and 3:

- Organization of the workshop "Climat et Impacts" (C. Colin, C. Hatté) 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).

- Lucie Bazin Troussellier is hired since the 3rd of November.

Axis 2:

- Bret Metcalfe and Carmen Alvarez-Castro will begin their post-doc positions at the end of 2016 or very beginning of 2017.

Axis 3:

- Hans Renssen is invited for one month by labex L-IPSL for model-data confrontation. The invitation is made through the senior scientist invitation program

Program until 2019

1- Data syntheses (axis 1)

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

1-a-i – Compilation of the mid to low latitude records covering the last interglacial period with dating constraints (Nov 2016-January 2017).

We will gather the mid to low latitude records (speleothem, marine cores, corals…) with a resolution better than 2000 years. We will select sites with available information on temperature (quantitative estimates), stable isotopes (quantitative estimates) and precipitation (qualitative estimates) as well as dating constraints. A workshop will be held at the beginning of the project (Climat et Impacts, Orsay, 15-16 November 2016) to promote collaborations with research team outside of the labex to complete the available records at L-IPSL.

1-a-ii- Evaluation of dating constraints and harmonisation of chronologies by geographic zones (Feb-Sept 2017)

First, we will perform a thorough evaluation of dating constraints of the sequences identified in the previous section. Second, the validated data gathered in previous section will be separated in different geographic zones (Mediterranean Sea – North Atlantic – Asia – Southern ocean). This will enable synchronization tests. We will thus use the DATICE multi-archives dating tool to incorporate these non-climatic dating constraints within each region to evaluate the robustness of the classical hypotheses of synchronicity of events among the various archives tracers. These tests will permit a quantification of the lags between similar events recorded in different tracers (e.g. lag between change in pollen concentration in response to a change in precipitation archives in $\delta^{18}O$ of speleothem).

1-a-iii – Production of a coherently dated sequence of the last interglacial period (Oct 2017-March 2018)

We will start 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. Coherence will be checked and optimized with South America speleothems. In addition, coherence within the Southern Ocean region will be achieved by optimizing marine sediment paleomagnetic records, chronological constraints and low latitudes proxies of ice cores and available speleothems in New Zealand. Finally, the coherent time frame will be transferred to the Indian and Pacific Oceans (using paleomagnetic and benthic foraminifera $\delta^{18}O$ records) for which less records are available.

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

1-b-i- Review of the high to low latitude records with robust dating constraints covering H2 and H4 (April 2017-July 2018)

An internal meeting will be held in mid 2017 to gather the different data sets available within L-IPSL and from the existing databases. In the following months (mid 2017 – mid 2018), an in-depth work on the reliability of dating constraints to be used over this time period will be assessed by experts in dating techniques within L-IPSL (e.g. ^{14}C correction).

At the end of 2018, a final selection of the high resolution records will be performed. This will be done by choosing the higher resolution records (one reference by large geographical zone) for rapid event H2 and H4.

1-b-ii Acquisition of new data on targeted periods (2017-2018)

The data acquisition addressed by this project should concern key dating constraints or archives with high resolution (200 years minimum around H2 and H4) and for which chronological constraint already exist or are currently acquired. Target projects for master 2 students within L-IPSL will be proposed for spring 2017 and 2018.

1-b-iv- Chronology improvements and synchronization tests by proxies or geographic zones (August 2017- June 2018)

In order to use the loess records for the global synthesis, we need to improve their chronological framework by using the dating tool DATICE multi-archives in which we will implement the possibility to deal with hiatus or erosion as well as complex chronological trends (opposed time evolution in eolian units and paleosols). This will also enable us to assess robust sedimentation rates and thus to constrain the IPSL-CM model for a realist and quantitative estimate of the dust-climate retroactions.
Second, the data gathered in previous section will be separated in different geographic zones (e.g. Mediterranean, North Atlantic, Asia, Southern Ocean). This will enable first synchronization tests as for the interglacial period.

1-b-iv – Production of a coherently dated sequences over H2 and H4 (July-Sept 2018)

The method for the production of the climatic and environmental sequences is exactly the same as the one given in part 1-a-iii. 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 FORAMCLIM

2-a-i Implementation of a FORAMCLIM interface so that it is easily run with IPSL, and eventually iLOVECLIM output (Jan – June 2017)

Currently, running FORAMCLIM requires many steps including corrections for present-day biases and regridding. 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. This work can directly be applied for first analysis of existing IPSL simulations for mid-Holocene, early Holocene, MIS3 and MIS4 stages (the LGM simulation has aleady been performed).

2-a-ii- Implementation of a method enabling the use of FORAMCLIM with the outputs of iLOVECLIM (July 2017- June 2018) and applications (July – Dec 2018).

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 (Jan – Dec 2017)

The comparison between paleodata on vegetation (pollens) and vegetation model outputs (ORCHIDEE) are limited because ORCHIDEE models the presence and productivity of different plant functional types which are not directly comparable to pollen counting. We will implement and 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. Specific output from climate model usually require special post-treatment if we want to use a model such as BIOME. We will create an interface to use BIOME with IPSL and iLOVECLIM output and test different methods for these bias corrections. 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 manpower.

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

In the next five years, our goal is to build new data bases for the periods of interest in this project, to improve our models and their capacity to compare their results with data and to perform these comparisons. This will yield a better knowledge or the processes at stake during the last interglacial warm period and the abrupt climatic changes of the last glacial period. We thus propose the following sub-challenges or deliverables:

Deliverable D1 - A **well-dated** and **global** data synthesis of the last interglacial (temperature, precipitation, 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 (e.g. 130, 125, 120 and 115 ka – kiloyears before present -, in addition to the 127 ka and 116 ka time slices selected as part of the PMIP4 and CMIP6 projects).

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

2.2.2 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)*

Participants

LMD – EMC3, ABC(t), DPAO
Frédérique Cheruy, Chantal Claud, Frédéric Hourdin, Jordi Badosa, Hélène Chepfer

LOCEAN – PARVATI, NEMO
Juliette Mignot, Myriam Khodri, Claude Frankignoul, Guillaume Gastineau, Kenshi Izumo, Jérôme Vialard, Francis Codron, Nicolas Lebas, Serge Janicot, Julie Deshayes, Gurvan Madec, Eric Guilyardi

LATMOS – SHTI, SPACE
Marjolaine Chiriaco, Slimane Bekki, Alain Hauchecorne, Marion Marchand, Franck Lefèvre, Sophie Bastin

METIS
Florence Habets, Laurence Lestel

IPSL - SIRTA
Martial Haeffelin, Jean-Charles Dupont, Sophie Cloché

LSCE - PALEOCEAN, GLACCIOS, PISP
Pascal Yiou, Philippe Naveau, Valérie Masson-Delmotte, Anne Juillet-Leclerc

External collaborators: Didier Swingedouw (EPOC, Université de Bordeaux)

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's 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.

Note that the methodology proposed here has slightly evolved over the year, after inputs of external reviewers and internal discussions.

Progress so far

The different tasks of the project are still progressing rather independently. Year 2016 has primarily been devoted to advancing on task 1.2. A report regarding volcanic activities (which ended in August 2016) has been sent separately. Regarding the solar forcing: the objective of the study is to test how the chemistry-climate IPSL model reproduces satellite-derived correlations between solar forcing and atmospheric composition, with a specific focus on the ozone and more generally to test its capacity to reproduce links between solar variability, stratospheric ozone and climate. For this, the chemistry-climate IPSL model is forced by different solar reconstructions.

The figure below shows the links between solar variability and ozone for the period 10/1991 to 8/2007. It shows the average ozone response to UV variability (here named sensibility) in an ensemble of 5 chemistry-climate simulations. The mean sensibility profile changes little over 3 year intervals. This shows that the response is not sensitive to the phase of the 11 year cycle. Nevertheless, the dispersion of the 5 simulations is clearly weaker during the maxima of the cycle.

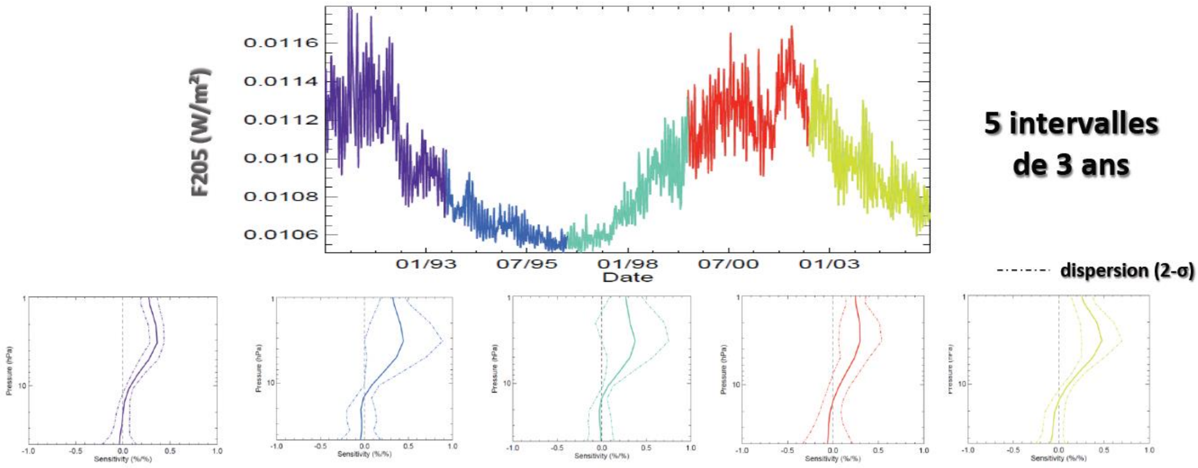


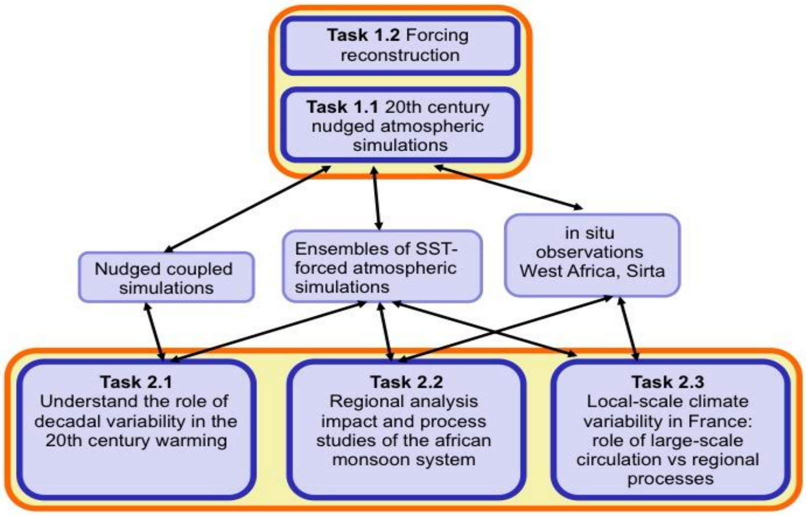
Figure : (top) time evolution of the incoming flux at 205 nm (F205 en W/m2) over the 18 years period; (bottom) vertical profiles of sensitivity to stratospheric ozone (% of the ozone variations for 1% of F205 variation) for each 3 years interval of this 18-years period, from 10/1991-9/1994 (descending phase of the cycle 22) to the period 9/2004-8-2007 (descending phase of the cycle 23). The dashed lines show the dispersion (2-sigma) around the mean of the 5 members The 5 intervals of 3-yrs are shown with different colors.

Atmospheric climate reconstructions with the atmospheric and land-surface models under development for CMIP6 are in construction for the (1958-2014) period (task 1.1). For the nudged reconstruction, the large-scale dynamics is constrained to the ERA-40/ERA-Interim re-analysis in order to reduce large scale biases from large scale dynamics misrepresentation. These reconstructions are carefully analysed to evaluate the realism of the near surface climate especially over land and identify sources of uncertainties.

As of task 2.1, one of the strategy foreseen to guide the climate model in coupled mode has been fully examined in perfect model configuration and published (Ortega et al 2016). This new strategy is based on the use of sea surface temperature only to constrain the model, with a variable restoring coefficient which increases proportionally to the mixed layer. The constraint is thus stronger when the surface signal has to be incorporated on a deeper physical layer. As indicated in the document, task 2.2 deserves some internal discussion and coordination probably with LP3. It will thus start later. Task 2.3 will begin as soon as possible when the post-doctorant will arrive. Datasets to be used in this task are already available, so the scientific analysis will start immediately. The first step of the analysis will consist in characterizing meteorology at local scale, using temperature and precipitation distributions for a given large-scale circulation, and studying the relation between these two parameters at different scales, and their evolution.

Program until 2019

The project in itself has to take off during 2017 and the program until 2019 is essentially to achieve the different tasks proposed in the project. This figure recalls how the tasks depend on and feed each other.



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	Task 1.1

	aerosols (e.g. dust) external forcings and implementation 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

Budget for 2016-2019

Staff – already decided in mid 2016

Task 1 Task 1.2.1: Solar forcing (R. Thiéblemont) 110 keur
Task 1 Task 1.2.3: Volcanic forcing (V. Poulain) 55 keur
Task 2 Task 2.1: Methods for coupled reconstructions 110 keur
Task 2 Task 2.3: Variability at local scale, over Paris area 110 keur

Staff – additional costs (to be confirmed and started 2017)

Task 1 Task 1.1: Forced reconstructions 110 keur
Task 2 Task 2.2: Variability at regional scale (West Africa) 72 keur

Total Staff 567 keur

Costs related to temporary staff confirmed in 2016
Laptop for travelling purposes x3 (post doc of task 1.2.3 already hired and equipped)
3*2keur
Attendance to international conferences: 1/ post doc effectively working in 2017 (flight and local transport, subsistence, conference fees) **3*1.5keur**
Publications: 1/ post doc effectively working in 2017 **3*2keur**

Costs related to temporary staff to be confirmed in 2017
Laptop for travelling purposes x2 **2*2keur**
Attendance to international conferences: 1/ post doc (flight and local transport, subsistence, conference fees) **2*1.5keur**
Publications: 1/ post doc **2*2keur**

Total other 27.5 keur

2.2.3 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 J(METIS) Gilles Billen (METIS) Ludovic Oudin (METIS) Christophe Rabouille (LSCE) Laurent Bopp (LSCE) Josiane Ronchail (LOCEAN) Claire Lazareth (LOCEAN) Vincent Chaplot (LOCEAN) Robert Vautard (LSCE) Mathieu Vrac (LSCE)	Alberto Borges (Belgique) Nathalie Gypens (Belgique Pierre Regnier (Belgique) Goulven Laruelle, (Belgique) Ronnie Lauerwald (Belgique) Philippe Cugier (IFREMER, France)

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.

In West Africa, for example, deciphering between climate variability and climate change and their impacts on societies through agriculture is a very challenging task. As global warming in this region of the world will affect numerous sectors such as energy, agriculture, water use and health, the time of emergence can differ and some sectors and/or some populations can be affected faster than some others. Knowing which sector will be first affected by climate change can help to support adaptation policies. In the warming Arctic and subarctic where permanently frozen soils dominate water and soil retention, climate change has already impacted the thermal structure of the surface soils. It is thus essential for the potential positive feedbacks that thawing permafrost can provide on the carbon cycle to understand how this impact will propagate on the permafrost thermal state, affecting water catchment hydrology, groundwaters and the mechanical stability of the soils in Arctic and subarctic regions. In addition, in all regions impacted by climate change, it is also crucial to assess the vulnerability of ecosystems to climate change, due to the importance of ecosystem services and goods (food production, water quality, soil retention and transfer downstream, connectivity between ecosystems). In this regard, aquatic ecosystems are of main importance as they transfer water, nutrients, carbon and particles downstream to the coastal zone and sustain in itself a large productivity that serves as food reserves for a large share of the world population (>50% for freshwater bodies, Kummu et al, 2011).

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:

- West Africa where water resources and agriculture are largely dependent on climate and its variability/change
- Arctic and subarctic regions where the water cycle, from surface to groundwaters, is impacted by climate change with potential feedbacks on greenhouse gases
- Densely populated mid-latitude regions where water quality and aquatic ecosystem services from land to coastal ocean are threatened

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.

Sub-project 1: Impact of climate change on water resources and agriculture in West Africa : a time-of-emergence approach (started in October 2016)

Uncertainties affecting climate model simulations are reflected in impact studies, which are based on climate models outputs. Global climate models display a significant spread in prediction over West Africa due to their divergent capabilities to model the West African Monsoon (WAM), which is the main rain carrier in the region. Therefore, reducing (or being able to quantify) the uncertainty of climate models in West Africa would provide impact models with more constrained inputs. 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 definition of critical metrics to evaluate climate models, based the sensitivity to specific mechanisms and/or forcings, and the subsequent classification, appears crucial in this respect (see below).

Sub-project 2: Impact of climate change on arctic and subarctic regions : the impacted water cycle from surface to groundwaters (started in 2016, post-doc to be hired in 2017)

The project will be based on a combination of an international modeling benchmark project and the development and of a unique reference field database on surface and subsurface hydrology in the Siberian Lena River Basin. The study of the system in the context of climate change will thus benefit from well validated and optimized codes to represent coupled Thermo-Hydrological codes operating at the scale of a landscape unit with the full complexity of field conditions. The international InterFrost code inter-comparison project hosted at LSCE (wiki.lsce.ipsl.fr/interfrost/) was launched in November 2013. Its intention is to provide a platform for the evaluation and optimization of coupled heat and water transfer codes and activate the modeling community around climate change impact issues requiring rapid development of efficient and validated codes. So far, academic test cases were considered with some validation experiments performed in a cold room at GEOPS. For the next phase to come, more realistic and complex test cases have to be developed and modelled, especially including non-saturated water flow conditions. In this purpose, time series measurements (started since 2012) performed in Central Yakutia (East Siberia) will be continued and compiled into a unique reference river-valley monitoring setup and database. A transect through a river and its underlying permafrost is instrumented in collaboration with the Melnikov Permafrost Institute in Yakutsk to continuously monitor the hydrological and thermal state evolutions. This dataset will be further prepared to become a reference InterFrost test case with web site publications and submitted to the InterFrost community.

The key parameter studied will be permafrost temperature and put in relation with the evolution of climate conditions. Its evolution is complex, e.g. depending on land cover, presence of a water body, presence of ground ice. The key issues addressed are here water resources evolution (all year round liquid water is only available below water bodies where the unfrozen bulb, called talik, will increase and might become a through-talik, able to connect surface and sub-permafrost water with very different geochemical properties) and landscape evolution (Yakutsk area is a ground-ice rich region where propagation of summer heat at depth can reach the ice rich layer of the ground thus causing liquid water to be released and the triggering of ground subsidence leading to the creation of thermokarst lakes).

The time of emergence of climate change will be studied for various key parameters covering all typical sub-units of the valley-river system (0°C isotherm propagation, permafrost temperatures at distinctive locations) taking past monitoring data into account (air temperatures since 1830, ground temperature series beginning in 1930 as well as recent monitoring at Syrdakh river site) and past and future regional climate simulations issued from CMIP5 and Arctic CORDEX. Some key ToE issues will be proposed for InterFrost participants providing the base to extend the results obtained with Cast3M (LSCE code) to several other codes possibly adopting other modeling strategies thus providing a range of uncertainties in terms of quantitative ToE results.

Sub-project 3: Impact of climate change on water quality and aquatic ecosystem services from land to coastal ocean: nutrient and carbon transfer

The project will extend the ongoing work of a L-IPSL project related to the impacts of modified hydrological regimes on the ecological functioning of aquatic ecosystems (Mélanie Raimonet, WP4 post-doc until September 2017), using a mechanistic biogeochemical model (pyNuts-Riverstrahler) at a pluri-regional scale. This modelling effort presently integrates a process-based understanding of fluvial nutrient and carbon exports from the upper watershed to the estuary. The development of this model and its test in one case study in the Seine River basin and estuary is presently finishing.

The present project aims at generalizing the hydro-biogeochemical modeling chain GR4J - pyNus-Riverstrahler – C-GEM over all the north-east European Atlantic rivers (from the Rhine to the Guadalquivir) with the introduction of carbon exchange fluxes between aquatic ecosystems and atmosphere; at assessing the response of the aquatic continuum to climate-induced changes for these rivers flowing into the Atlantic coast; at quantifying the time of emergence (ToE) of the impacts on these systems over the present variability; and at establishing high resolution budgets of GHG emissions from regional aquatic continuum especially CO_2 exchanges with the atmosphere, and contribute to the revision of their impact in global Earth System model estimates under changing climate condition.

Progress so far

Sub-project 1 which is the most mature has started in 2016.

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 precipitation variability at time scales from interannual to multidecadal is mainly driven by global ocean SST anomalies [Rodríguez-Fonseca et al., 2015], but also drivers at the regional scale are important, as the Saharan Heat Low (SHL) [Lavaysse et al., 2009], which is in turn modulated by the radiative forcing from CO_2 [Cook and Vizy, 2015], Saharan dust [Lavaysse et al., 2011], and water vapour [Evan et al., 2015]. Unfortunately state-of-the-art climate models are still deficient 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. in review). Summarising, the open issues regarding the WAM dynamics and precipitation variability and change can be conveyed in two main issues: (1) the comprehension of the physical mechanisms; (2) the ability of the models in simulating the identified physical mechanisms and the sensitivity to different forcings.

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 definition of critical metrics to evaluate climate models, based on the sensitivity to specific mechanisms and/or forcings, and the subsequent classification, appears crucial in this respect.**

The project will be developed through the following actions:

- **Identification of key areas and indicators for impact assessment:** namely, agriculture (crop production), water resources (drought risk), human health (heat stress), energy (availability of renewable sources);
- **Analysis of climate models:** existing climate simulations, mainly from the CMIP5 archive, will be analyzed to build a classification process-oriented, i.e., based on the sensitivity to different forcings (SST, GHG and aerosol) and the model ability in reproducing the main physical mechanisms (global teleconnections, regional feedbacks);
- **Application of climate outputs to impact indicators:** simulated climate variables will be used to run crop models and compute impact indicators.
- **Process-oriented assessment of the impacts:** impacts will be assessed for each of the model family previously identified, to verify whether the model classification is suitable for building impact scenarios or a finer classification is requested.
- **A time of emergence analysis** will be performed on climate inputs and impacts outputs to determine when climate change impacts will emerge from present-day climate variability.

So far, Marco Gaetani has been hired as a postdoc in LOCEAN to work on the project on October 1st. He has started to read the papers and participated to a meeting with Mathieu Vrac (LSCE) and the team in LOCEAN (Serge Janicot, Benjamin Sultan, Moïse Famien, Dimitri Defrance) on methodological aspects (time of emergence studies, choice of runs) and future works.

Program until 2019

A series of workshop will be conducted with 2 workshops in 2017 and one per year in 2018 and 2019. The first two workshops will be dedicated to methodological issues of time of Emergence and regional climate uncertainties and projections, while the last two workshops will be dedicated to cross presentations of time of Emergence in different contexts related to the three subprojects.

Two subprojects will start in 2017 and will last until 2019:
- Impact of climate change on arctic and subarctic regions: the impacted water cycle from surface to groundwaters
- Impact of climate change on water quality and aquatic ecosystems services from land to coastal ocean: nutrients and carbon transfers

SP2. Impact of climate change on arctic and subarctic regions: the impacted water cycle from surface to groundwaters (lead C. Grenier-LSCE and F. Costard-GEOPS)

The project includes two main components. The first one concerns the development and evaluation of local process oriented Thermo-Hydraulical codes that can simulate the complex short and long time evolution of key landscape units under climate change. This is the overall aim of the InterFrost benchmark project in which the LSCE coupled TH LSCE Cast3M code is involved. The second concerns the studied system. A river-valley system was selected in the key region of Central Yakutia with a collaboration with the Melnikov Permafrost Institute (Yakutsk). A combined approach is considered to: i) complement and compile local Syrdakh river pilot site monitoring information, ii) simulate of the system with Cast3M over the monitoring period, iii) select and adapt (bias correction) past and future centennial climate evolution conditions based on climate simulation (CMIP5 and Arctic CORDEX) and local meteorological histories, and iv) based on these, study address the ToE issues, study the main system controlling parameters and provide a prospective of its future evolution. The unique Syrdakh database will be proposed to the InterFrost community. Due to the complexity of the natural system and code properties, simulation approaches among the presently 13 participating codes will necessary differ allowing inter-comparison of modeling approaches (from simple to complex) and of simulation results.

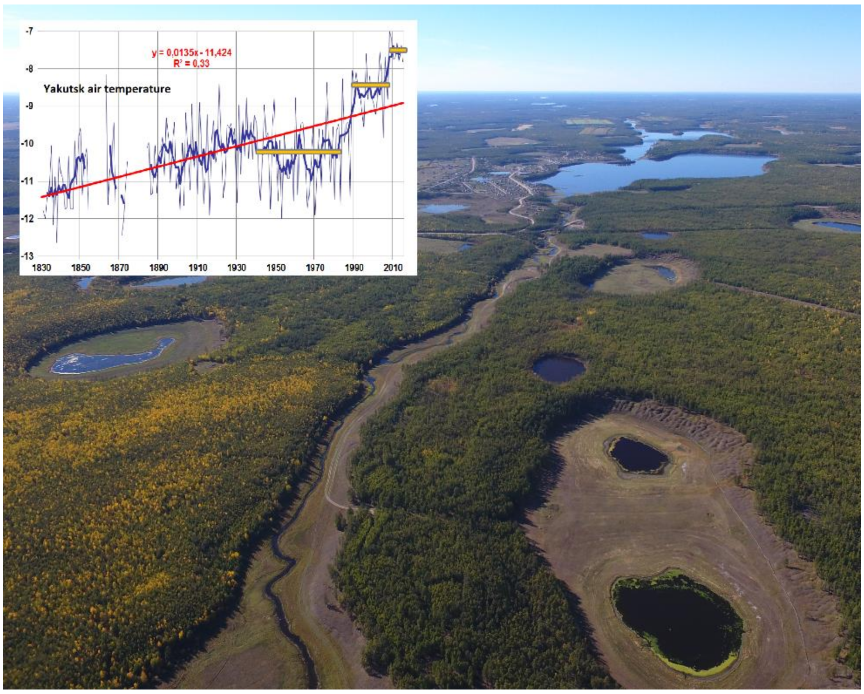


Figure: Drone view of Syrdakh region with the river valley with a thermokarst landscape, air temperature histories are provided from 1830 on.

The working program is structured as follows:

- **Task 1**: Global to regional climate simulations
    a. Review existing model results from CMIP5 and Arctic CORDEX for CY (Central Yakutia)
    b. Select a short list: reject models that are not adapted to permafrost conditions and/or unable to represent existing time series (e.g. T_{air}, Precip)

c. Implement bias correction approaches and propose optimal time series for last and next centuries

- **Task 2**: Local impacts on the Syrdakh Pilot Site river-valley system (river, valley, meadow and pine forest covers)
    a. Complement ongoing field studies (e.g. implement some key measurements complementary to thermal monitoring like soil water content probes and/or geophysics like GPR or resistivity).
    b. Create a comprehensive and well-structured database for the Syrdakh site monitoring period (from 2012 on) to be published on the InterFrost web site.
    c. Simulate thermal state evolution during monitoring period with Cast3M (+ additionnal models from InterFrost project)
    d. Simulate past and future system evolution with ad hoc scenarios
    e. Sensitivity analyses to main parameters and extrapolate predictions to other typical CY river-valley systems

- **Task 3**: Time of emergence and controling parameters
    a. Atmosphere, ground & talik parameters from a combined analysis of observations and models
    b. Time to reach thresholds for start of ice wedge melting and through talik installation for typical CY systems

InterFrost aims are to propel the development and validation of efficient and realistic thermo-hydrological models to address the climate impact issues on small scale systems not represented in climate models. The dataset collected in Siberia will be proposed as InterFrost task once the dataset is gathered. The main tasks devoted to InterFrost are

- **Publication** of the first phase of the inter-comparison (13 codes on cases TH2 and TH3, refer to wiki.lsce.ipsl.fr/interfrost/), a preparatory step to the present project
- **Organization of a workshop** in late 2016 or beginning of 2017 to precise future tasks:
    a. Extension of the model development and evaluation issues to **non-saturated flow conditions** based on the most recent know-how. Review and reconsider existing laboratory cases to assess such issues and a future inter-comparison strategy. Climate simulation codes are already interested to join on this issue.
    b. Include **realistic field cases** for common simulation and inter-comparison, esp. the **Syrdakh case**.

A post-doc will be hired in 2017 to work on this program in close relation and making the link between simulation and field data participants, climate modeling and regional process oriented participants, prepare the Syrdakh dataset to communicate with the InterFrost participant community via web site publishing, publish the results in international journals.

SP3. Impact of climate change on water quality and aquatic ecosystems services from land to coastal ocean: nutrients and carbon transfers (lead V. Thieu-METIS and C. Rabouille-LSCE)

Global biogeochemical cycle's assessments have for long underestimated or oversimplified the transport of carbon and nutrient in watersheds, across the aquatic continuums. IPCC Assessments only recently accounted for the lateral flows of carbon, based on new research emphasizing its contribution to global and regional budgets (Battin et al. 2009, Bauer et al. 2013, Raymond et al. 2013, Reignier et al 2013). While research on nutrient cycling have rapidly integrated the filtering role of aquatic system (Meybeck and Vorosmarty 2005), biogeochemical models operating at large scales remain mainly (semi-)empirical (Global : NEW2 - Mayorga et al. 2010; European : GREEN - Grizzetti et al 2011; US : SPARROW - Alexander et al. 2001) and do not represent the physics and the variability of processes governing the functioning of aquatic ecosystems (Billen et al 2009; Garnier et al 2002). In addition, estuarine interfaces (involving multiple space and time scales dynamics) are often limited to well-constrained specific systems, and hardly ever consider in regional or global integrated land to sea assessment.

Global budgets thus required to be confronted with (and potentially enhanced by) regional models' assessments, as they are the only ones offering a comprehensive **biogeochemical accounting** of the transformation, elimination/immobilization of carbon and nutrients during their **transfer from small stream to larger river and finally to estuaries ad the coastal ocean**. These regional models are also prompted to help in **quantifying the cascade of climate-induced changes** along the aquatic continuum, which potentially includes both *direct* impacts on hydrological regimes and temperature, and *indirect* impacts on river ecosystem functioning, i.e. the biogeochemical response of the aquatic continuum to climate-induced changes in the hydrological cycle.

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

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 a view of a generic application at the continental scale, this modeling chain is currently tested on the Seine river basin (75,000 km^2, 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).

In SP3, the understanding of the carbon fate from land to ocean is of great importance and the modeling chain will directly benefit from the most recent progress on this research topic, in collaborations with scientists from the ITN C-Cascade (led by P. Regnier) which among other includes the improvement of the carbon dynamic within the pyNuts-Riverstrahler model (A. Marescaux, ongoing PhD). In addition, The UMR Metis has been collaborating since more than 25 yrs with several labs of the ULB and IFREMER, coupling our river basin model with their coastal zone models (EU-EROS, EU-Thresholds, EU-AWARE, and several projects of the Liteau program), while the LSCE group is actively involved in understanding river-sea connection in major regional rivers.

These recent or on-going researches will forms the basis of a dynamic modelling research framework, from which SP3 will take full benefits. SP3 research works will progress through the following achievements:

1. Generalizing the hydro-biogeochemical modeling chain GR4J - pyNuts-Riverstrahler – C-GEM over all the north-east European Atlantic (NEA) rivers (more than 350 000 km of drainage network from the Rhine to the Guadalquivir). Previous research has enabled to set up and validated the pyNuts-Riverstrahler for the recent period on the NEA domain (SEAS-ERA EMoSEM, Desmit et al. 2014) making the SP3 modeling exercise easier for the freshwater compartment. Most effort will be devoted to the generic application of estuarine C-GEM which reduces data-requirements by using

an idealized representation of the estuarine geometry and allows quantitative prediction of hydrodynamics, salt transport and biogeochemistry at the appropriate spatial and temporal scales in alluvial estuaries. The scale of application (NEA domain) represents a main breakthrough for the river-estuary modeling chain.

2. Use the modeling chain to provide an integrated assessment of the aquatic continuum response to climate-induced changes for all western European rivers flowing into the Atlantic coast. Beyond the amount of carbon and nutrients exported to coastal area (where it might support harmful algal bloom), SP3 will grant a particular attention to the spatial and temporal assessment of aquatic ecosystems alterations along the gradient of climatic conditions offers by the NEA domain. Additionally, comparative analyses of individual NEA aquatic systems responses are expected (including hydrosystems morphology, climate conditions, estuarine geometry etc.). These outcomes should open promising discussions and collaborations with marine modelling teams (IPSL – LSCE – LOCEAN).

3. Main impacts brought out by the modelling chain in response to climate changes will be subject to concept of the time of emerge (ToE), in order to determine when climate change impacts will emerge from present-day climate variability. Dedicated meeting will be held early in the project to define how to apply a common methodology and define metrics in the case of aquatic continuum.

4. Establish high resolution budgets of GHG emissions from regional (NEA) aquatic continuum especially CO_2 exchanges with the atmosphere, and contribute to the revision of their impact in global Earth System model estimates under changing climate condition. Beyond serving as regional benchmark for the global models, these regional emissions assessments should also provide useful quantitative information related to climate dynamic and feedbacks for Earth System models developed at IPSL.

We propose the following agenda for SP3:

	2016	2017				2018				2019			
SP3 Impact of climate change on water quality													
	Generalizing the hydro-biogeochemical modeling to NEA												
	integrated assessment of response to CC												
	Times of Emergence												
	CO2 emissions from regional aquatic continuum												
	Datasets deliverable						x		x			x	
	Scientific paper achievement				x				x			x	

It appears important that SP3 starts in mid-2017 (ideally in June or July), to enable a joint time period where M. Raimonet (WP4 postdoc) could transfer the methodological developments produced in Labex project 15, in an efficient way to the SP3 postdoc candidate.

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	March 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	March 2018
Time of emergence of impacts and simulation of future impact of CC on river-valley system	Paper	Fall 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

Budget for 2016-2019

Sub-project 1:

Two-year Postdoc from Oct 2016 to Sep 2018 (with 5-10 years experience) 110 000 €

Publication charges: 1500 euros x 2 papers	3000 €
Conference travels: 1500 euros x 1 year	1500 €
Total SP1	**114 500€**

Sub-project 2:

Interfrost workshop 2016	7000€ (déjà dépensé)
Interfrost workshop 2017	4000€
22-months Postdoc (2017-2018)	103000€
Field trip in Siberia: 2750€ x 4 (two per year)	11000€
International conference: 1500€	1500€
Total SP2	**126 500€**

Sub-project 3:

Two-year Postdoc from Jul 2017 to June 2019	110 000 €
Publication charges: 1500 euros x 2 papers	3000 €
Conference travels: 1500 euros x 1 year	1500 €
Total SP3	**114 500€**
Total LP3	**355 500€**

2.2.4 Model development (TWP1)

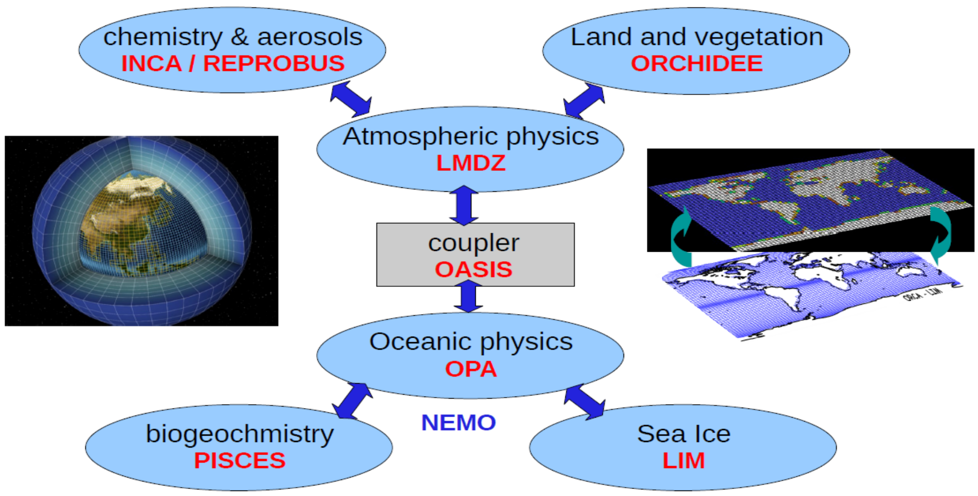
Project lead: Jean-Louis Dufresne, Olivier Boucher

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 ICMC 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 ICMC 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 in 2016 for the former and in late 2017 for the later. A next generation version that will use the new DYNAMICO dynamical core for the atmosphere is in development for a use in 2018. 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.

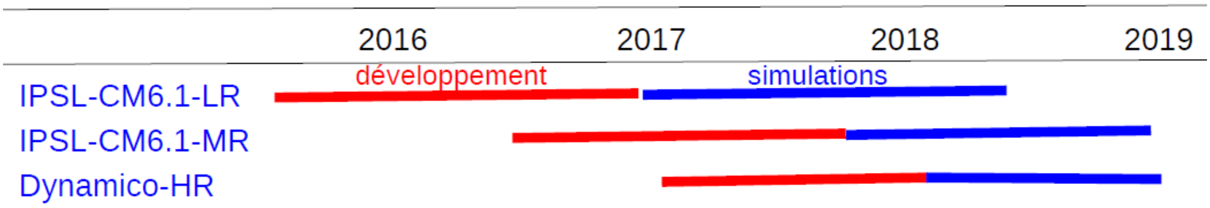
In the next two years, our work will be very much oriented by our contribution to the sixth phase of the CMIP project. We have obtained a large amount of computer time and storage volume during the period 2016-2018 that will allow us to have an ambition contribution to CMIP6. We plan to contribute to 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 [TBC], Oce: 0.25° 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 beginning 2017. Test and improvements to prepare higher resolution version of the model has 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: 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.

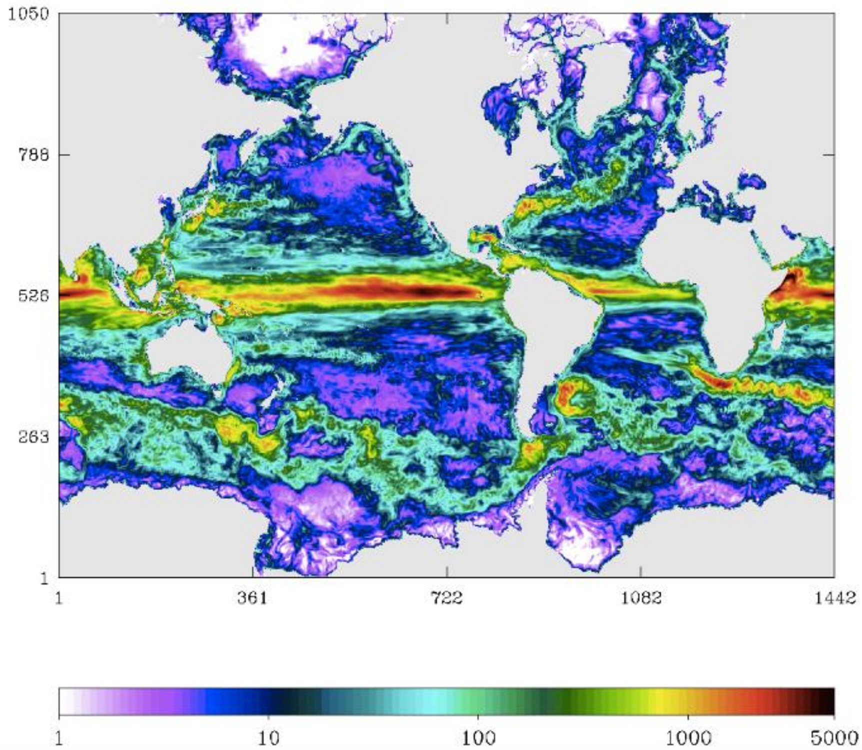


Figure : Eddy kinetic energy for year 1999 (run started in 1981 from climatology and rest, and uses CORE2 atmospheric forcings) in the model grid framework (colors follow log scale, unit is cm2/s2) for a simulation with the eORCA025 model.

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 keuros

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 (starting late 2016): 60 keuros

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 for high resolution simulations (2018): 60 keuros

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

2.3 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 last call for Invited Scientist open in October 2015 allowed to found 3 proposals among the 6 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. The call will be re-conducted in 2017.

Inviting Laboratories	Invited Scientist	Status	Duration	Topic
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.

2.4 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 new total	**242 333**
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	**390 594,5**
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	**127.5 355,5**
Model Development	2016-2017	Software Engineer	55
	2016-2017	Post-doc Ocean Modeling	55
	2017-2018	Software engineer	55
		Computing & conferences	15 20
		Total Model Development	**125 185**
Foreign Scientists	2016	2 visits for 2016	**30**
Foreign Scientists	2017	2 visits for 2017	**30**
Total		*Total*	**914.5 1528**

Table of expenses for the long-term phase of the LABEX. Numbers in black indicate expenses that were budgeted in the 2015 Action Plan. Red indicates total new expenses including additional decided in this plan.

2.5 Publications (depuis le début du LABEX)

The list below only mentions published articles referring directly to the LABEX grant and not those not referring the LABEX but using the LABEX tools or facilities. Sources Web of Science, Google Scholar.

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13. Cordero Llana, L., et al., 2015 : IPSL Arctic Metadata portal, Data Science Journal, in press.
14. Delanoë J. M. E., Heymsfield A. J., Protat A., Bansemer A., Hogan R. J. Normalized particle size distribution for remote sensing application, Journal of Geophysical Research: Atmospheres, 2014, 119 (7), pp.4204-4227
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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. The capacity of L-IPSL to transfer knowledge and innovation has concretely focused on three aspects so far:

- Innovative instrumentation for environment observation and monitoring;
- Climate services;
- Support on data sets for climate services;

This report summarizes actions undertaken in this perspective

3.1 Innovative instrumentation

Our goal is to achieve a meteorological lidar system which can be described in different versions and different technologies (Raman, DIAL). One of these versions must meet market demand which can be very diverse in terms of potential customers.

As a research laboratory, we aim to make autonomous and validated lidar instruments, but also to develop the data processing algorithms associated with the complexity of these instruments. These works are not only carried out in the laboratory, but they have the advantage of also being conducted during field campaigns where instruments are subjected to various stresses associated with the meteorological environment. This brings us further in technology readiness level.

The proposed potential transfer is based on several ascertainments:

- Lidar are high-tech instruments difficult to implement and maintain, use is a matter for specialists.
- The acquisition cost is high (> 130 k €), equipment needs to be widely used to be profitable, occasional use is not of industrial profitability.
- Analysis and processing of data requires advanced expertise that is not widespread. It is nevertheless present and recognized in certain IPSL laboratories such as LSCE and LATMOS.
- The aerosol lidar market suffered a crisis following the abrupt end of the activity of operation and maintenance of aerosol lidars sold by the Leosphere Company.
- New instruments (meteorological lidar, DIAL water vapor lidar, ozone DIAL lidar) are being developed or are already deployed that might interest the industrial world.

This set of findings appeared to us as leading international markets of interest:

- Operational agencies (Météo-France, ANDRA, Met Office, NASA, …)
    - Data analysis
    - Management & maintenance of instrumental network
- Environmental / government agencies (China, USA …)

- Expertise for pollution measurements (megacities, industrial complex)
- Data analysis

- The industrial environment (small businesses, large industrials)

  - Foresters
  - Monitoring of pollutant emissions

- Some research laboratories

  - Data analysis
  - Maintenance and developments

Expected deliverables (1/2 page)

There are two main deliverables that are:

- The results of market research and customer canvassing
  - List of customer requests mainly oriented data analysis for lidar systems of various types: water vapor, temperature, wind, aerosol and ozone.
  - Financial market assessment by differentiating the different types of lidar and, industrial, operational and institutional actors.

- The proposal of a business model if the return is positive.

Progress so far (2 pages)

The progress is along three strategic directions needed for the industrial transfer: the instruments, the algorithms and a first market study.

Water vapor channel.

A new version of the water vapor Raman channel is now developed and was involved in the framework of PARCS (Pollution in the ARCtic System) of the French Arctic Initiative. This new channel is associated with two cross-polarized channels for atmospheric aerosol studies, all constitute the lidar WALI (Water vapor and Aerosol Lidar). The laser has been upgraded and its emitted energy is now enhanced by a factor of 3. The emitting path was modified to meet the eye-safety requirements, which is preferable for a democratic use of the lidar.

The error budget of an instrument is better constrained when using the instrumental synergy which can be offered by a field experiment. The PARCS experiment held in Hammerfest (Norway) implicated ULA (Ultra Light Aircraft) flights with a payload including a meteorological probe. When comparing the vertical profile of water vapor mixing ratio derived from both the lidar and the ULA (Figure 1), the relative root mean square difference is computed to be less than 0.4 g/kg of water vapor mixing ratio. The threshold needed for meteorological purpose is thus reached.

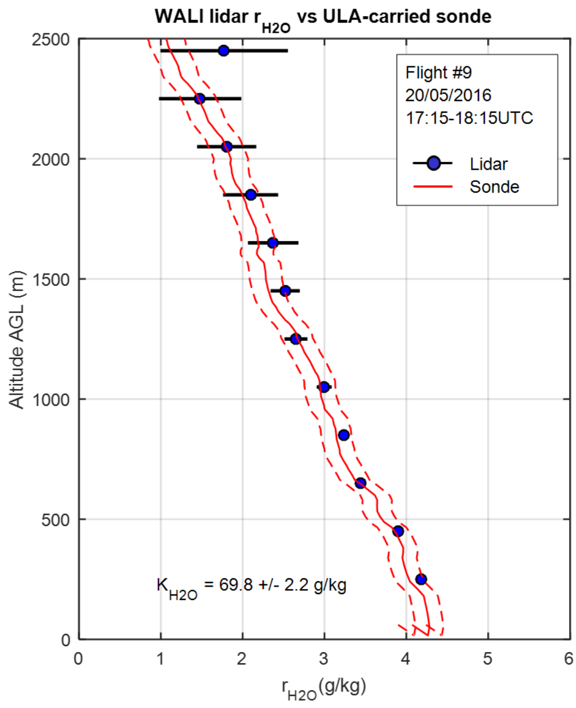

Figure 1: Atmospheric water vapor mixing ratio derived from both the WALI lidar and the meteorological probe embedded on an ULA. The standard deviations on the measurements are also shown (horizontal bars for the lidar and dash lines for the meteorological probe).

Temperature channel

In parallel to the implementation of the water vapor channel, the feasibility studies on the temperature channel were continued. A specific optical bench has been designed and both the upgrade of the laser (wavelength stabilization by injection seeding) and the optical components (high rejection filters) are ordered.

We aim absolute error on the thermodynamic temperature less than 1°K. The simulator gives the results plotted in Figure 2 for the spectral responses given in the insert. During night-time, the standard deviation of 1 K is reached for the distance from the emitter of ~8 km. During day-time this value decrease to ~2-3 km due to the solar background. For a good optimization, the spectral responses of the interferential filter depend of the solar background level. For night, it is preferable to select rotational lines far from the Cabannes line (centred on the laser wavelength). It is the opposite for the day because the rotational line strengths are larger close to the incidence wavelength. Yet an optimum can be found between the two (insert).

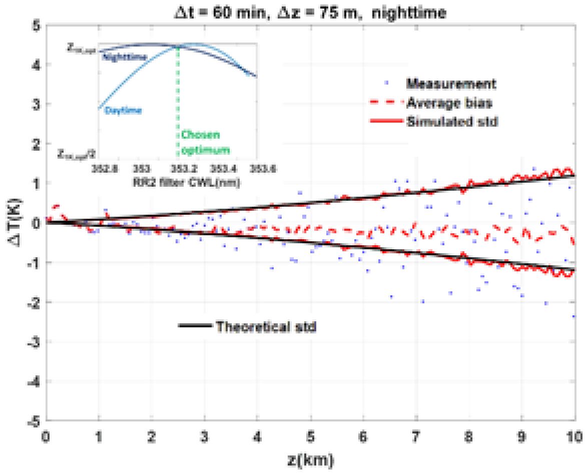

Figure 2: Theoretical assessment of the temperature error against the distance from the emitter.

Airborne Raman lidar

Both the simulations and the first test on the airborne Raman lidar conducted in 2015 led to the upgrade of the laser (30 mJ instead of 16 mJ) for improving the signal to noise ratio. The upgraded instrument flight during the Arctic campaign of May 2016.

Algorithms

One of the main goal is to improve the data analyses using automatic algorithms. This development is ongoing but needs to be adapted with the potential markets. Figure 3 gives an example of the retrievals for different aerosol layers which can be identified with the so called "lidar ratio" (LR).

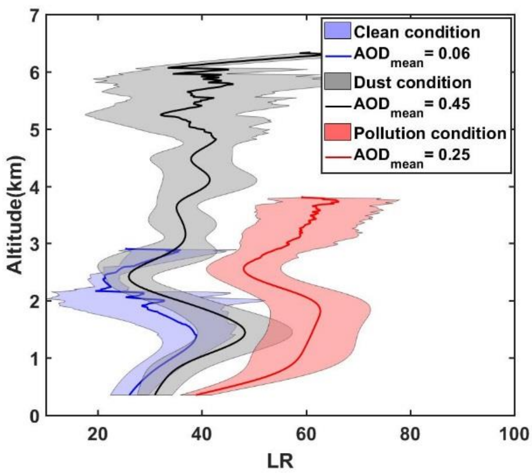

Figure 3: Vertical profile of the Lidar ratio for different aerosol types seen on the Mediterranean coast. The standard deviations are given by the filled areas.

Market research

A first market research has been performed by the SATT Paris-Saclay. The interviews were on 9 interlocutors from academic, operational and industrial activities. They were mainly oriented towards the instruments (mainly aerosol lidar) and their maintenance and did not yet cover important aspects of the knowledge transfer. The findings are not very optimistic, but still limited to mainly French interlocutors.

The European market (French, England and Germany) on aerosol lidar is very limited, it is occupied by Sigma Space / Envicontrol and Raymetrics. It is mainly oriented towards airports and air traffic control. Prospects are expected for DIAL lidar with clients already identified but also new constraints to be respected (first lidar on the market in less than a year).

For service activities related to aerosol lidar maintenance, they are dependent on the sale of equipment and represent a very small market. For the market deserted by Leosphere, it will be very difficult to recover because of the loss of customer confidence. In the case of a recovery of confidence, only an annual maintenance is required. Sigma Space lidar are advertised as open in terms of software. There is no information to Raymetrics. In the operational world, the collection of data may not exceed 3 hours after acquisition. This is of the order of the day for AASQA. However, these various structures do not have the financial potential to acquire lidar instrumentation, even less to build a lidar network.

Envisaged activities, potential markets for a new lidar business (1 page)

In the coming year, we will finalize the meteorological lidar system by including the temperature channel in which the various components have been specified following a numerical link budget study. The instrument will then be tested on the atmosphere and compared with radiosonde measurements and / or airborne measurements. We are considering the use of small drones to perform the calibration of the lidar system in the lower atmospheric layers (< 400 m amsl).
A document showing the characteristics of the lidar system will be edited quickly to be used for customer canvassing. Such a document will consider the measurement accuracy that can be achieved using both the simulator and the observations that have been acquired during the lidar tests. A similar document will be produced for the water vapor DIAL relying mainly on digital simulator available at LATMOS.

A major activity will be an enlarged market study to be conducted by a high-tech expert consulting company, using dedicated funding within the WAVIL ANR project. Overall, we insist that this study will focus primarily on service and not on the actual instrumentation. Indeed for the instrumental part, the transfer is envisaged via existing companies that have the ability for building a rugged lidar from an initially tested instrument by a research laboratory. This activity is now determined to be too risky and too costly for it to be led by a start-up company.

We remain confident that a serious need exists for an operational meteorological lidar network in Europe, from years of discussion with the French and German weather agencies. It will have major benefits for our understanding of extreme events due to precipitations as well as other cloud and aerosol physics.

3.2 Climate services

In 2013, the L-IPSL elaborated a strategy in the field of climate information transfer for adaptation, the so-called “climate services”. This strategy 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.

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.

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. 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).

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 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. Pilot studies with SMEs

Four projects for transfer actions IPSL - SMEs were launched, and an additional one is currently being discussed and will be subject for a call for tender. These actions are still underway. Here are the summaries, but a progress report can be found in Appendix B.

P1: Generation of bias corrected CMIP5 and CORDEX essential climate variables data set. Start of the TCDF spin-off. The goal of this 18 month 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. 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 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. 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).* During the project several computational modules are developed to perform the calculations as well as apply quality control procedures both on technical specifications (ESGF file standards) as well as a data check (outliers detection). As of December 2016, development and technical testing of the chain is almost over and the development phase will be finalized by January 2017. What remains to be done is the so-called "production" phase that is the generation of the data set. 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 scientist 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.

P2: **A « proof of concept » innovation project on statistical sub seasonal forecasting, using an analogue method. ARIA Technologies is participating to this project.** See the Report in the Appendix B. In a nutshell, the project aims at investigating the potential of a new *stochastic weather generator* based on atmospheric circulation analogues (AnaWEGE) for seasonal predictions. The plan is to test the performance of this tool to simulate the spread of climate trajectories at a time scale between days and seasons. This tool can generate large ensembles (at least several hundreds of members, on a desktop computer in a few minutes) of climate variables, and compute their probability distributions. On the market side, ARIA Technologies made several studies on the impact of climate change. It was found that most potential clients are interested in subseasonal climate prediction and uncertainty. In the present project, ARIA Technologies gets acquainted with the modified code of AnaWEGE and will conduct the tests, with the assistance of IPSL. A Masters student (Mariette Lamige; Université de Lyon 1) was hired for 5 months for an internship at ARIA and LSCE (May 2015 to September 2015). The first step was to modify the code of the stochastic weather generator AnaWEGE code into a predictive mode. The second stage was to test the stochastic predictions against observations. Predictions are done in hindcast mode for winters between 2000 and 2010. Probabilities of temperature anomaly sign was predicted and verified against persistence and climatology. In deterministic mode, as a preliminary result, we find that the predictions of correct anomaly sign is above 60% up to Day 8 for Paris temperature. The skill appears to be lower in Toulouse. In all cases no skill was found beyond this lead time. Seasonal skill should be further investigated in the next phase of the project.

P3: **A project to study the possibility of transfer of the LMDz model to a SME (Aria Technologies) for different climate applications)**: More and more applications connected with weather or Climate issues require high resolution 3D gridded data and use the WRF model nested in global output such as GFS or ECMWF analyses or forecast. The use of LMDz software developed by IPSL/LMD could provide a new and innovative solution including several competitive differences. In the context of the present work, we plan to carry out and evaluate several downscaling runs and to assess their possible interest in the fields of air quality and water management. The main test here is in replaying with LMDz some of the SECIF (IPSL ANR project) cases and in comparing the results obtained with those obtained previously with the WRF model. The LMDz model code was transferred and implemented on ARIA computers. A first training session was carried out. The selected SECIF case is a domain around Roman –sur –Isere (Alps Mountains) and tests on heavy rains have been done. Numerical problems on our cluster are fixed but some modelling issues remain to be solved with IPSL team assistance. The project has been delayed for several reasons and we expect more results in the next report

P4: Project to develop a platform for adaptation to climate change and phyto-sanitary risks in agriculture. 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 be able to construct different adaptation strategies. The project started at the end of 2016 and its results are expected in the course of 2017. IPSL will work with ECOCLIMASOL for this purpose, which will develop the product platform, based on interaction with researchers. IPSL. Expected results will include: (i) a mainstream interactive web-based platform to visualize the impacts of climate change on the agricultural sector; (ii) an interactive web platform allowing practitioners to test virtually different agricultural practices to optimize their adaptation In the context of climate change, (iii) continuous improvement of the calibration of key models, methods and diagnoses for agricultural adaptation to climate change. The developed platform, here for South America, will be designed to be easily adapted to the end of the project to other parts of the globe, including France and Africa.

P5: A project on carbon budgets and their evolution in large forests. In the field of "GHG monitoring services" (GHG) at different scales, for example for cities (Paris and Recife, Brazil) and for forest areas (Landes forest), IPSL Will work to improve the modeling of carbon fluxes in large forests, based on observations of carbon fluxes and stocks on the forest basins studied. This will be done with a subcontractor which will develop his expertise in this area.

5. 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

IPSL has now also submitted 2 applications, one of which IPSL has the lead, and which are in review, in the field of core services for regional climate projections. New tenders could provide new opportunities.

It is to be noted that during 2016, IPSL has also been involved in several bids submitted to the ERA4CS programme, for the development of climate services.

For next phase, proposed LABEX support:

The Climate services strategy will pursue its initial phase, with ongoing projects. An update of the strategy will be made in 2017 [this has been delayed by the number of external projects, including the new ERA4CS program] after the end of the first projects, as it is too early currently for lessons learnt. For 2017, the LABEX will focus on a few actions:

- Further developing the IPSL-SME program, by finalizing the first four projects, and launching the last one. Funding devoted to these projects appear in previous plans, and are more concretely:
    - 123 400 euros for the IPSL-TCDF project
    - 37 000 euros for the IPSL-ARIA project on analogs prediction
    - 60 000 euros for the IPSL-ARIA project on LMDz transfer
    - 85 000 euros for the IPSL-ECOCLIMASOL project on agriculture
    - A budget of 70 000 euros is reserved for the project on forests.

The total budget for this program is therefore 375 000 euros

- Further supporting the development of C3S Copernicus projects at IPSL by hiring a climate science officer who will ease the links with stakeholders, help in writing proposals and reports, and develop innovative climate service ideas. A budget of 130 K€ 2-year salary for a scientist with experience, travel) was already approved in the 2015 plan, but applications came lately in the year and are being reviewed currently. In addition, given the load of Copernicus projects and the administration and management level required, as well as the ERA4CS activities, it is proposed that the LABEX fund a 2-year project manager (100 K€). An additional budget for travel and stay for preparing and completing C3S and ERA4CS projects is provided (20 K€).

- A new national-scale climate service development program has recently been proposed in several initiatives (MEEM program). This program follows up a number of initiatives such as DRIAS, EXTREMOSCOPE, the GICN, and a new portfolio of climate service demonstrators. This was proposed lately in January 2017 to the MEEM). This is a joint program with Meteo-France, CERFACS, in collaboration with BRGM. The ambition is to extend the program later to other ALLENVI partners. In case of success it was suggested to complement the funding by a 1-year research position in order to foster the development of the integrated modeling chain climate services at national level. The proposed funding is 60 K€.

In addition, a 2-year Labex climate service science officer was budgeted in 2015, but the hiring will only take place in 2017. The cost is estimated to 110000 euros (incl. travel and publication). The cost was accounted for in the previous action plan.

New proposed actions starting in 2017:

Actions	PA 2016
Copernicus Climate Change & ERA4CS support Project manager	80000
C3S and ERA4CS support to travel	15000
Support to National Climate Service development	60000
TOTAL CLIMATE SERVICES	**170000**

3.2.3 Support on Data set for climate services

Leads : M. Chiriaco (LATMOS), J. Lopez (IPSL), C. Boitel (LMD)

A new action has been developed in 2016. This project of IPSL Pôle Observation to improve provision of Earth observation datasets for Climate services and other applications. In this report, we present the technical developments of ReOBS project, that are currently supported by the LABEX-IPSL (innovation) through employment of Julio Lopez. Scientific aspects are only synthetized in the annex by a list of publications.

Goals

The objective of the ReOBS project is to present a scientific approach to aggregate and harmonize about fifty geophysical variables at hourly scale on a decade, to allow multiannual and multi-variables studies combining atmospheric dynamics and thermodynamics, radiation, clouds and aerosols, from ground-based observations. Actually, there are many datasets from ground-based observations in the world, that have a significant scientific value as they contain complete and precise information on the long-term, due to their spatio-temporal collocalisation. But they are under-used, in particular the observation synergy aspects, because of their complexity and diversity (of calibration, quality control, treatment, format, temporal averaging, metadata…). This project has two main objectives: (1) developing a set of methods available for the community to process ground-based data robustly and reliably at a hourly time scale over one decade or more; (2) providing a single netCDF file based on observations carried out at a multi-instrumented supersite (e.g. SIRTA observatory), containing about fifty substantial geophysical variables hourly averaged over a decade for the oldest ones, easily usable by the scientific community. In this project, observations are “re-analyzed”. This “re” prefix applies to six main steps: calibration, quality control, treatment, hourly averaging, homogenization of the formats and associated metadata, expertise on more than ten years of observations. In contrast, previous studies (i) only take into account some of these six steps for each variable, (ii) do not aggregate together all variables in a single file, (iii) do not offer an hourly resolution for about 50 variables on a decade (for the oldest variables). The ReOBS approach can be applied to supersites other than SIRTA and to additional variables. The main implication of this work is that complex observations are made readily available for scientists that are non-experts on measurements.

Figure 1 summarizes the ReOBS approach. ReOBS is the approach proposed by ACTRIS-FR to improve the ability of users to utilize data from the French atmospheric supersites.

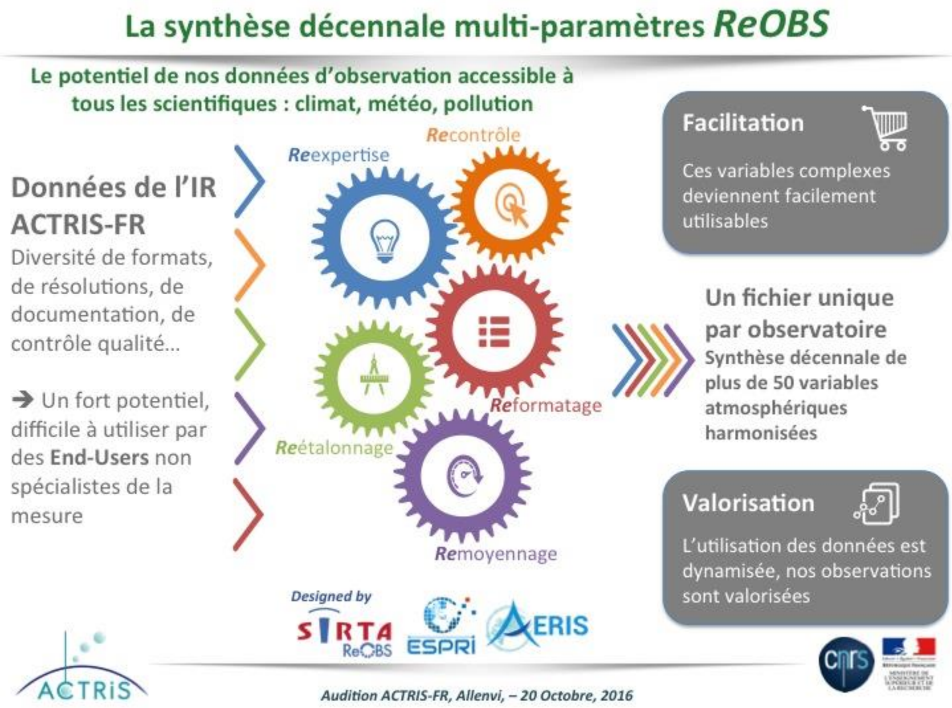

Figure 1: The ReOBS approach endorsed by ACTRIS-FR.

Expected deliverables

The goals defined for ReOBS project will result in the follow technical products:

- Production tool
- Production implementation on AERIS centers for data and services
- Production based on data from several atmospheric observatories
- Pre-requirement for input datasets to be processed
- Production of data to be included in different data communities
- Algorithm developments
- Technical documentation including user guide

Production tool. An easy to use code written in Python and bash, able to take in charge the complexities of create a multi sources file. This code is designed to ensure:

- Evolution (add/delete parametres)
- Maintenance (code partially generique, test/correction of traitements processes)
- Portability (easily implementation for production)
- Production optimisation (possibility of choice for traitement processes)
- Production monitoring
- To meet the requirements for the production of CDR to contribute to the supply of national and international projects (obs4mips, ACTRIS, …)

Production implementation on AERIS centers for data and services. Each center works with its own resources and ways of production. The simplicity in the design of the code that creates ReOBS and its modular aspect allows it to be implemented on centers specialized in data production. This implementation will allow mutualisation of expertise and production for national and international communities.

Data production from several atmospheric observatories. ReOBS file is currently created only based on SIRTA data, but the production tool is be able to create ReOBS files for observations from other sites

Pre-requirement for input datasets to be processed. A document that describes requirements that the datasets must have in order to be processed by the ReOBS production tool, this document specifies all the formats that can be handled and the necessary metadata that conforms to different standards.

Production of data to be included in different data projects. The ReOBS production tool will generate data that can be processed by other codes (ex : CMOR) in order to be able to participate in national and international observation data networks (ACTRIS, OBS4MIP).

Algorithmic development. Improvement in production of variables derived from observations and algorithms and research of innovation for optimization in quality controls.

Technical documentation. A user guide is developed and a set of documents that describes (1) the architecture of the code, (2) methods for keeping the maintenance and evolution, (3) choices of treatments and quality controls, (4) the creation of variables.

Progresses so far

The heritage of a complex and heterogeneous production system that used to create ReOBS files was the main reason for conceiving a new architecture (figure 2 and figure 3).

Some aspects in the development of the ReOBS production tool are already done:

- Conceptual framework
- Choice of code languages
- Creation of prototype processes
- Choice of variables
- Choice of filing architecture

We already started the work for production implementation on AERIS (or ACTRIS) centers for data and services by defining the metadata and the Pre-requirement for datasets to be treated. The metadata was directly modified in NetCDF on the final ReOBS file and in the new prototype processes. A document was created in order to establish the Pre-requirement of data and metadata to be treated.

The studies of actual quality controls have been done (based on both static and dynamic thresholds). Other techniques are under study such as FFT filter, rolling mean and median. These techniques are being testing by us in some variables seeking the improvement of our quality controls.

The production and evolution of ReOBS file is continuous, the ReOBS files are updated every 6 months and distributed online on a dedicated website http://sirta.ipsl.fr/reobs.html.

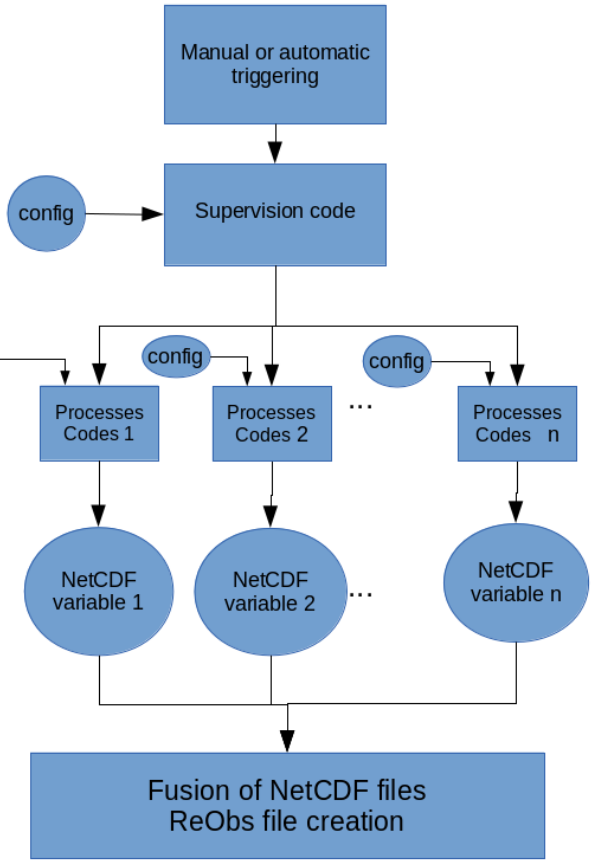

Figure 2: ReOBS processing chain

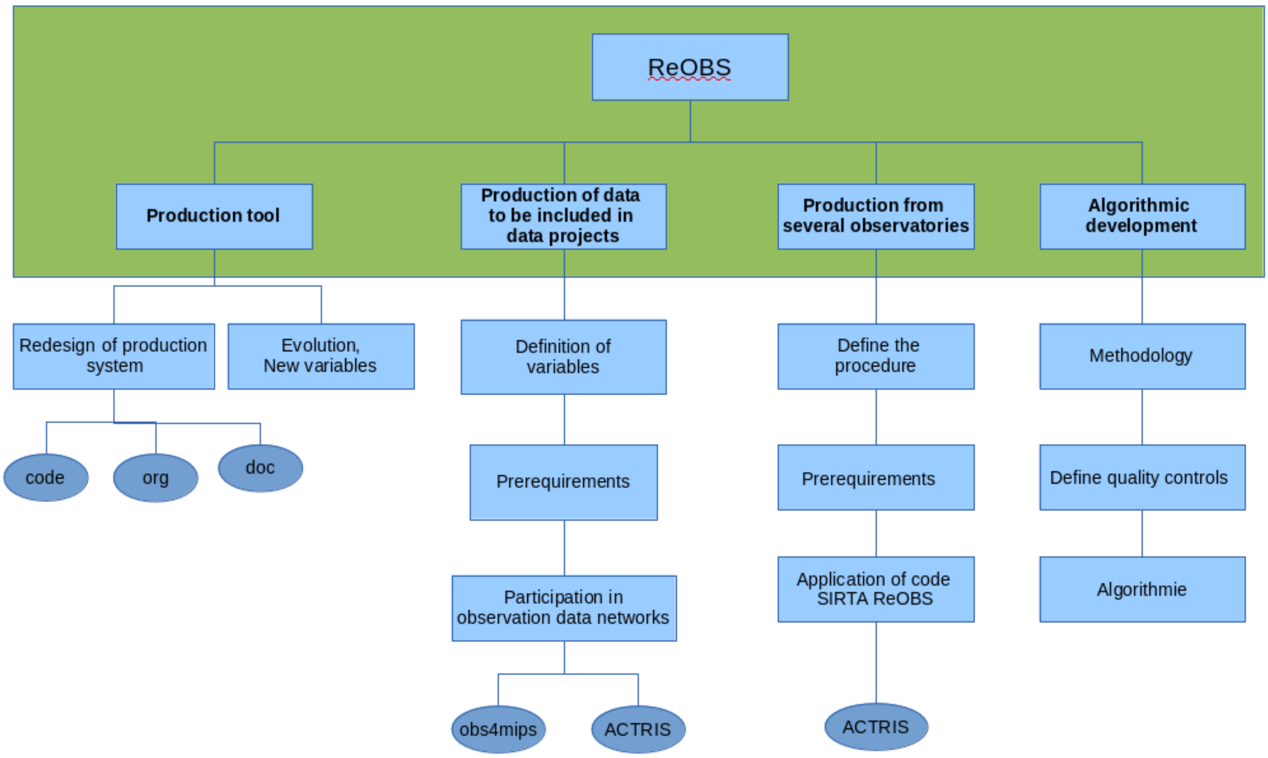

Figure 3: global view of ReOBS project

Table 1 shows the progress of the 7 sections of the work (number of months already done and future work).

	Done	Future work
Production tool	2 months	4 months
Production implementation on centers for data and services	1/2 month	2 months
Data production from several observatories	1/2 month	3 month
Pre-requirement for datasets to be treated	1 month	1 month
Production of data to be included in different data projects	1 month	3 month
Algorithmic development	1 month	2 months
Technical documentation	1 month	2 months

Table 1: progress by section: first column is what has been done, second column is for future work.

1. Envisaged activities, potential markets for companies

Next steps of the work are to continue and finalize the 7 sections, following the repartition indicated in Table 1. Emphasis will be placed on actions required for the application of the ReOBS approach to other sites than SIRTA. Implications of this work occurs at different levels:

- **ACTRIS-FR Research Infrastructure**: ACTRIS-FR RI federates the French research groups and instrumented supersites for the observation of atmospheric water, aerosols, and reactive gases. The ReOBS approach has been discussed in this group since the beginning. Currently, we work on applying ReOBS to other ACTRIS-FR sites.
- **DEPHY (LEFE) project**: ReOBS development and SIRTA-ReOBS using for model evaluation are part of one DEPHY work-package. Some model evaluations studies have been published already.
- **AERIS**: AERIS will be solicited to support the implementation of ReOBS in one of the AERIS center for the data production. Discussions with AERIS about implementation will be initiated in the first half of 2017.
- **ACTRIS**: The H2020 European project ACTRIS-2 gathers the European scientific community working on the ground-based observations of aerosols, clouds, and reactive gases. Discussions have started in ACTRIS-2 for applying ReOBS approach to European sites, taking advantage of the important amount of data with well-identified algorithms and quality approach.
- **ARM**: The ARM network is the United States equivalent of ACTRIS. Since the beginning, the ReOBS approach is inspired from the ARMBE development, and is partially the results of collaboration between Europe and United States concerning the observation of the atmosphere

- **CMIP6 and OBS4MIP**: IPSL is strongly involved in CMIP6 via IPSL model simulations, but also via contributions to observation databases developed specifically for comparisons to simulations, realized for the OBS4MIP project. Until now, OBS4MIP only contains data from satellite measurements. One of our objectives is to add ReOBS datasets to OBS4MIP. It requires adaptations for matching OBS4MIP standards (CMOR format essentially).

Annex: Scientific publications and contribution to conferences and workshops, based on ReOBS

In preparation:

Chiriaco M., J. Bados, J.-C. Dupont, J. Lopez, M.-A. Drouin, M. Haeffelin, S. Bastin : SIRTA-ReOBS : a homogeneization work on the long-term multi-parameters of SIRTA supersite. *In prep.*

Chiriaco M., H. Chepfer, S. Bastin, M. Haeffelin : Which clouds have a cooling or a warming effect at SIRTA ? *In prep.*

Articles dans des revues de rang A à comité de lecture

Dione C., F. Lohou, M. Chiriaco, M. Lothon, S. Bastin, J.-L. Baray, P. Yiou, A. Colomb, 2016: Influence of synoptic circulations and local processes on temperature anomalies over three French observatories. *JAMC, in press.*

Bastin S., M. Chiriaco, P. Drobinski : Control of radiation and evaporation on temperature variability in a WRF/MED-CORDEX simulation, 2016: comparison with collocated long term ground based observations near Paris. *Clim. Dyn.*, pp 1 – 19.

Haeffelin M., S. Crewell, A. J. Illingworth, G. Pappalardo, H. Russchenberg, M. Chiriaco, K. Ebell, R. J. Hogan, F. Madonna, 2016 : Parallel developments and formal collaborations between European atmospheric profiling observatories and US ARM research programs. *AMS Monograph*, 10.1175/AMSMONOGRAPHS-D-15-0045.1.

Chiriaco M., S. Bastin, P. Yiou et al. 2015 : Dry soils exacerbated 2006 heatwave in Northern France. *Science for Environment Policy, European Commission's Environment Directorate-General.* Highlight of Chiriaco et al. 2014. Issue 405.

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Cheruy F., J. C. Dupont, A. Campoy, A. Ducharne, F. Hourdin, M. Haeffelin, M. Chiriaco, 2013 : Combined influence of atmospheric physics and soil hydrology on the realism of the LMDz model compared to SIRTA measurements. *Clim. Dyn.*, DOI 10.1007/s00382-012-1469-y.

Pal, S., and M. Haeffelin (2015), Forcing mechanisms governing diurnal, seasonal, and interannual variability in the boundary layer depths: Five years of continuous lidar observations over a suburban site near Paris, J. Geophys. Res. Atmos., 120, 11,936–11,956, doi:10.1002/2015JD023268.

Conferences

Chiriaco M., S. Bastin, P. Yiou, M. Haeffelin, M. Stéfanon, 2014 : European heatwave in July 2006 : how local processes amplify favourable large-scale conditions. *Gewex conference, La Hague.*

Bastin S., M. Chiriaco, O. Bock, S. Somot, P. Drobinski, L. Li, 2014 : Evaluation of MED-CORDEX simulations using long-term ground-based multi-sensors observations and GPS data. *Gewex conference, La Hague.*

Chiriaco M., S. Bastin, P. Yiou, 2013 : Complementarity of CORDEX runs and ground-based observations to evaluate the contribution of large-scale circulation to temperature variability around Paris. *CORDEX Conference, Brussels, Belgium*.

Bastin S., J.-F. Rysman, M. Chiriaco, J. Delanoë, Y. Lemaître, 2013 : Evaluation of MED-CORDEX simulations using lon-term ground-based observations and A-Train satellite data. *CORDEX Conference*.

Chiriaco M., J. C. Dupont, L. Klenov, M. Haeffelin, P. Siebesma, H. Klein Baltink, E. O'Connor, F. Cheruy, 2011 : Synthesis of ground-based atmospheric measurements from 3 European observatories : their utility for climate model evaluation in the framework of EUCLIPSE. *Meeting CFMIP*, Exeter.

Chiriaco M., J. C. Dupont, M. Haeffelin, L. Klenov, F. Cheruy, S. Bony : Synthèse de 10 ans d'observation de l'atmosphère au SIRTA : utilisation pour l'évaluation des modèles de climat dans le cadre d'EUCLIPSE ; *AMA 2011, session DEPHY*, Toulouse.

<u>Workshops</u>

M. Chiriaco, H. Chepfer, S. Bastin, M. Haeffelin, V. Noël : Quantifier et comprendre la contribution des nuages à la variabilité de la température au SIRTA. Journée SIRTA 2016, Palaiseau.

M. Chiriaco, H. Chepfer, S. Bastin, V. Noël, M. Reverdy, M. Chakroun, J.-C. Dupont, J. Badosa, J. Lopez, M. Haeffelin : Toward multi-decadal active sensor cloud observations using ground ans satellite-based measurements. ACTRIS science meeting, 2016.

Chiriaco M., S. Bastin, H. Chepfer, M. Chakroun, J.-L. Dufresne, F. Cheruy, S. Bony : Using lidar measurements and lidar forward operators to evaluate the representation of key-processes in regional climate simulations. Workshop TO-PROF (COST action), Paris, Décembre 2016.

Chiriaco M., J.-C. Dupont, J. Lopez, J. Badosa, M. Haeffelin, S. Bastin, C. Dione: Comment tirer profit des aspects multi-paramètres et long terme des observatoires : l'approche ReOBS. *AMA 2016, Météo-France Toulouse*.

Dione C., F. Lohou, M. Chiriaco, M. Lothon, S. Bastin, J.-L. Baray, P. Yiou, A. Colomb : Influence de la grande éhcelle et des processus locaux sur les anomalies de temperature observes sur toris observatoires français. *AMA 2016, Météo-France Toulouse*.

Chiriaco M., S. Bastin, P. Yiou, M. Haeffelin, J.-C. Dupont, M. Stéfanon : La canicule de juillet 2006 en France : comment des processus locaux ont amplifié des conditions de grande échelle favorables. *AMA 2016, Météo-France Toulouse*.

Bastin S., Bock O., Parracho A., Chiriaco M., B. Ahrens, D. Conte, M. Dominguez Alonso, L. Li, R. Roehrig, P. Drobinski: Evaluating multimodel variability of humidity over Europe using long term GPS network and ground base datasets. *9th Hymex workshop, Mykonos, Sept. 2015.*

Chiriaco M., S. Bastin, M. Haeffelin, J.-C. Dupont, J. Badosa, J. Lopez: Comment expliquer la variabilité du climat à l'échelle régionale? Utilisation de SIRTA-ReOBS. *Journée SIRTA 2015, Palaiseau.*

Dione C., F. Lohou, M. Chiriaco, M. Lothon, S. Bastin, J.-L. Baray, A. Colomb: Influence de la grande échelle et des processus locaux sur les anomalies de température : cas de trois observatoires de ROSEA. *Journée SIRTA 2015, Palaiseau.*

Lopez J., J. Badosa, M. Chiriaco, S. Bastin, J.-C. Dupont, M. Haeffelin, C. Boitel, M.-A. Drouin, L. Klenov : SIRTA-ReOBS : algorithmie, jeu de données actuel et perspectives. *Journée SIRTA 2015, Palaiseau.*

Badosa J., M. Chiriaco, S. Bastin, J.-C. Dupont, J. Lopez, M. Haeffelin: SIRTA-ReOBS: the multi-parameter homogenized and value-added database of the SIRTA observatory in Paris Region. *Missing Data workshop*, 2015.

Chiriaco M., J. Badosa, J.-C. Dupont, M. Haeffelin, S. Cloché: Synthetizing, homogenizing, aggregating different parameters observed at ground: the Re-OBS approach. *Copernicus workshop on climate observations requirements*. *Reading,* June 2015.

Badosa J., J. Lopez, M. Chiriaco, S. Bastin, J.-C. Dupont, M. Haeffelin, C. Boitel, M.-A. Drouin : SIRTA-ReOBS : la base de données multi-paramètreshomogénéisée et à valeur ajoutée de l'observatoire SIRTA. *Ateliers de Modélisation de l'Atmosphère 2015, Toulouse.*

Chiriaco M., S. Bastin, M. Haeffelin, J.-C. Dupont, J. Badosa, J. Lopez : Comment expliquer la variabilité du climat à l'échelle régionale? : apport de SIRTA-ReOBS. *Ateliers de Modélisation de l'Atmosphère 2015, Toulouse.*

Chiriaco M., S. Bastin, P. Yiou, M. Haeffelin, M. Stéfanon, 2014 : European heatwave in July 2006 : how local processes amplify favourable large-scale conditions. *BSRN workshop, 2014, Bologne.*

Chiriaco M., S. Bastin, H. Chepfer, J.-C. Dupont, V. Noël, C. Hoareau, P. Yiou : 10 ans de cycle diurne au SIRTA : une analyse en regimes de temps. *Journée SIRTA 2014, Palaiseau.*

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Chiriaco M., J.-C. Dupont, M. Haeffelin, S. Bastin, F. Cheruy : Réanalyses des observations sol (SIRTA). *Workshop EECLAT 2014, La Rochelle.*

Chiriaco M., J.-C. Dupont, M. Haeffelin, S. Bastin, F. Cheruy : Réanalyses des observations sol (SIRTA) pour des applications long-term. *Workshop DEPHY 2013, Paris*.

Chiriaco M., S. Bastin, P. Yiou : Impact des processus locaux sur la canicule de juillet 2006. *Journée SIRTA 2013, Palaiseau*.

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Cheruy F., A. Campoy, J.-C. Dupont, F. Hourdin, A. Ducharne, M. Chiriaco, M. Haeffelin, A. Idelkadi : Combined influence of the atmospheric physical and soil hydrology on the simulated meteorology at the SIRTA atmospheric observatory and in Europe. *Journée SIRTA 2012*, Palaiseau.

Bastin, M. Chiriaco, P. Yiou, H. Fréville, J.-C. Dupont, L. Klenov, M. Haeffelin : Utilisation des observations du SIRTA pour mieux identifier les processus expliquant la variabilité du climat régional en Ile de France. *Journée SIRTA 2012*, Palaiseau.

Chiriaco M., S. Bastin, J. C. Dupont, L. Klenov, C. Lebeaupin, H. Fréville, 2011 : Variabilité interannuelle des nuages en Ile de France : comparaisons SIRTA/WRF-CORDEX. *Journée CORDEX-IPSL*, Paris.

Chiriaco M., J. C. Dupont, M. Haeffelin, L. Klenov, S. Bony : Synthèse de 10 ans d'observation de l'atmosphère au SIRTA : utilisation pour l'évaluation des modèles de climat dans le cadre d'EUCLIPSE. *Journée SIRTA 2011*, Palaiseau.

Chiriaco M., J. C. Dupont, M. Haeffelin, L. Klenov, 2010 : Contribution to EUCLIPSE : The SIRTA and Cabaw Climate Testbed Dataset. *Meeting COST*, Cologne

Chiriaco M., J. C. Dupont, L. Klenov, M. Haeffelin, 2010 : Variabilité interannuelle de la couverture nuageuse en île de France. *Journée SIRTA 2010*.

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 propositions 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 have been launched 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 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 started in September 2015 as part of a climate label, which will be further developed during upcoming years. The next ambition here is to build a federal master on climate and environment in Ile-de-France, based on the complementary strengths of the different existing masters and IPSL laboratories.

Axis 2, Field & lab work. Practical training has been promoted by 1) the creation of a catalogue of existing lab sessions and field works; 2) the identification, development and innovation of few representative lab sessions and field works; and 3) the design and implementation of a one-week field training for 25 undergraduate students (first week organized with success in April 2016) on the experimental site of IPSL at Palaiseau (SIRTA)

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 were 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. Innovative numerical tools (Jupyter e-python notebooks) to perform online practical teaching sessions are under study to be deployed with L-IPSL (Jupyter server). Two practical works in statistics are already provided on the prototype platform and experimented.

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. Contacts are on-going to distribute this flyer and sent largely outside the academic world and advertise our training offer.

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” – “les messagers du climat”). 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 and early-phase management (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.

Short-term objectives

For the upcoming year, we plan to continue the on-going actions within each axis:

- 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

- Axis 2: Implementation of innovative numerical tools (Jupyter notebooks for lab and field works). 2nd edition of the one-week field training for undergraduate students.
- Axis 3: Development of numerical resources about climate and environment. For instance, we are going to develop such resources for undergraduate students (e-CaIPSuL project at UPMC). This project will be on the climate, paleoclimate, atmosphere, hydrology.
- Axis 4: Development of a network of non academic partners interested in professional training about climate change
- Axis 5: Continue to support and promote existing summer and winter schools for early-career scientists.

Long-term objectives

For the third part of the L-IPSL labex, we plan to 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. Implementing a federal master 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 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.

2. Proposing a path to fully integrate the numerical era (axes 1, 2, 3)

Enhancing the actions started in 2016, we propose to organize 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 (*TedX* model).

3. Developing 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 host (or make links towards) the lab and field works 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). Finally, the template and structure of the platform will be updated and improved.

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 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 2017.

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.

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 a provision of the same amount in 2018.

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 Meetings, professor « décharge » for organisation & module building, kickoff, …	12 k€
· Numerical era Online Content recording in specialized centres for L-IPSL scientists, licences for personal softwares, public event with presentation recording, advertising of the action	100 k€
· E-learning platform and content, sub-contracting, 5 k€/yr Management and maintenance of the platform	20 k€
· Links with research and innovation 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€)	25 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€***