EVALUATION LABEX 2018

DEMANDE DE LA PROLONGATION

OSUG@2020

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1 RÉSUMÉ : VERSION EN FRANÇAIS

La phase initiale du LabEx OSUG@2020 "Innovative strategies for observing and modelling natural systems" a été consacrée au développement de nouveaux instruments et méthodologies de collecte, d'analyse et d'interprétation des données concernant le Système Terre, les systèmes planétaires ainsi que l'univers. Mis en œuvre au sein de l'Observatoire des Sciences de l'Univers de Grenoble (OSUG), le projet couvre un large spectre de domaines scientifiques de l'astrophysique, aux sciences de la terre et de l'environnement, à l'écologie jusqu'aux sciences sociales. Le projet s'appuie sur les missions de l'OSUG, l'observation, la recherche, la formation et la diffusion des savoirs, avec de nombreuses interactions entre toutes ces missions. Il est soutenu par cinq organismes nationaux de recherche et trois établissements d'enseignement supérieur locaux, qui sont des atouts majeurs pour la réalisation de nos objectifs. OSUG@2020 a permis de tisser des liens entre ses unités de recherche et ses personnels, mais aussi avec des grandes infrastructures de recherche nationales et internationales dans les domaines concernés. Il a joué un rôle déterminant dans le développement d'un centre de données et de plates-formes analytiques. OSUG@2020 a contribué à promouvoir et renforcer les recherches interdisciplinaires, en particulier autour des enjeux Alpins à travers l'"Integrated Alpine Research System" et les recherches partenariales dans la zone intertropicale. De nouvelles méthodes d'enseignement ainsi qu'une instrumentation de pointe regroupée sur le Campus de l'Environnement ont été intégrées dans les cursus des universités participantes et dans des écoles d'été dédiées.

Tout en continuant à développer et à renforcer les réalisations scientifiques, techniques et structurantes qui ont marqué la première phase du projet, notre objectif pour la prolongation est de renforcer notre ancrage dans les réseaux dynamiques des infrastructures de recherche, des sites de terrain, des instruments, de l'expertise, des scientifiques et des disciplines. La mise en interaction de nos disciplines ouvre de nouvelles perspectives pour étudier les couplages complexes, les actions et les rétroactions entre les différents compartiments du système terrestre ainsi que son environnement stellaire et planétaire. Plus précisément, le projet est principalement axé sur l'acquisition de nouvelles connaissances autour du thème central de l'Habitability in changing worlds, avec des innovations de rupture attendues dans les domaines clés suivants : 1. Qu'est-ce qui rend et maintient les planètes habitables ? 2. Comment intégrer les multiples facettes de l'habitabilité sur Terre ? 3. Comment l'habitabilité est-elle maintenue avec des ressources limitées ? 4. Comment les aléas naturels et les risques associés contraignent-ils l'habitabilité ? Pour répondre à ces questions, il est nécessaire de poursuivre l'acquisition et le développement de nouveaux instruments et des plates-formes analytiques et de développer des approches innovantes pour le traitement et l'analyse de quantités de données croissantes en synergie avec des outils de modélisations multidisciplinaires et multi-échelles. En collaboration avec le LabEx ITEM, la "Mountain Research School" sera créée, dont l'objectif sera de transformer les connaissances scientifiques en solutions pratiques et de renforcer les actions transdisciplinaires science-société destinées en particulier à la population locale et aux acteurs socio-économiques confrontés aux changements radicaux dans leur environnement. Les actions innovantes en matière de formation seront renforcées pour promouvoir des approches interdisciplinaires pertinentes dans les cursus universitaires concernés et pour créer une nouvelle école d'été de haut niveau. Les actions de diffusion des savoirs à destination du grand public sont également prévues avec la Station Alpine Joseph Fourier qui rejoint le consortium, ainsi qu'avec le Planétarium des Moulins de Villancourt.

2 SUMMARY: ENGLISH VERSION

The initial phase of the LabEx OSUG@2020 “Innovative strategies for observing and modelling natural systems” has entirely been devoted to developing new instruments and methodologies for collecting, analyzing and interpreting data concerning the Earth, planetary systems, as well as the outer space. Implemented within the Observatoire des Sciences de l’Univers de Grenoble (OSUG), the project covers a wide range of scientific fields including Astrophysics, Earth and Environmental Sciences, Ecology, and also related Social Sciences. The project embraces all missions of OSUG, i.e. observation, research, education, and outreach, with numerous interactions between all these aspects. It is supported by five national research organizations and three local institutions for higher education, which are major assets for carrying out our objectives. OSUG@2020 has built strong links between its research units and individual members, but also with national and international research infrastructures in the fields of Astronomy, Astrophysics, Earth and Environmental Sciences. It was instrumental to implement a dedicated data center and analytical platforms. The LabEx contributed to the enhancement of interdisciplinary research with a specific focus on the “Integrated Alpine Research System” and strategic activities with intertropical countries. Novel teaching methods as well as state-of-the-art instrumentation regrouped in the “Campus de l’Environnement” were integrated into related curricula at the participating universities and into further educational activities such as high-level schools.

While continuing to develop and strengthen the major scientific, technical, and structuring achievements of the first phase of the project, our goal for the prolongation period is to enhance and rely on our dynamic networks of research infrastructures, of field sites, of instruments, of expertise, of scientists, and of disciplines. The further integration of our disciplines opens up new perspectives to study the complex couplings, actions and feedbacks between the various compartments of the Earth system as well as its stellar and planetary environment. Specifically, the project is mainly geared towards building new knowledge around the central scientific theme “Habitability in changing worlds”, with breakthroughs expected for the following key issues: 1. What makes and keeps planets habitable? 2. How can we integrate the multiple facets of habitability on Earth? 3. How is habitability maintained with limited resources? 4. How do natural hazards and associated risks contest habitability? Addressing these questions requires even more innovative instrumentation, additional analytical platforms and equipment, cross analyses of large bulks of data, advanced multiscale and multidisciplinary modeling tools, and the enhancement of the OSUG data center. In close collaboration with the LabEx ITEM, the “Mountain Research School” will be created with the goal of transforming scientific knowledge into practical solutions and enhancing transdisciplinary science-society actions intended in particular for the local population and socio-economic players facing drastic changes in their environment. Innovative education actions will be developed for the promotion of interdisciplinary approaches in relevant BSc and MSc curricula and for the creation of a new annual high-level school directly related to the central theme of habitability. Major outreach actions are foreseen at the Station Alpine Joseph Fourier, which is joining the LabEx, and via the planned local planetarium and exhibition center “Les Moulins de Villancourt”.

3 CONTEXT AND PREVIOUS ACHIEVEMENTS

3.1 CONTEXT AND SCOPE OF THE PROJECT

The LabEx *Innovative strategies for observing and modelling natural systems* (OSUG@2020) contributed to the **four major missions** of the *Observatoire des Sciences de l'Univers de Grenoble* (OSUG) (Fig. 1), i.e. performing and coordinating **long-term observations of astronomical and terrestrial systems**, carrying out **related research**, contributing to **academic formation** in concerned scientific disciplines, and **outreach and dissemination** activities (*Diffusion des Savoirs*). The project objectives aimed at strengthening links between observation and research (Work Packages WP-R1 to R3); enhancing higher education and international activities (W-HE) and promoting outreach and technology transfer (WP-V). OSUG@2020 fostered the integration of the institutes and research teams LECA, LEGI, Irstea, and FAME/LIPhy into the OSUG community and the merging of the *Laboratoire de Glaciologie et Géophysique de l'Environnement* and the *Laboratoire d'Etude des Transferts en Hydrologie et Environnement* into IGE in 2017. OSUG now regroups all local high-level research units and teams located in Grenoble performing research in Astrophysics, Earth Sciences, Environmental Sciences, and Ecology. With Irstea and Météo-France as supervising authorities since 2016, and in addition to CNRS and IRD, OSUG has now **close links to four national research organizations** active in its scientific domains. In 2011, OSUG lost its status of an academic educational department (*Unité de Formation et Recherche,* UFR) governing teaching programs at Bachelor (BSc) and Master (MSc) level. Nevertheless, OSUG@2020 contributed to the **structuring and excellence of educational programs at UGA** in our scientific domains, which are mostly integrated in the programs of the UFRs *Physique, Ingénierie, Terre, Environnement, Mécanique* (Phitem) and *Chimie-Biologie* (CH-BIO).

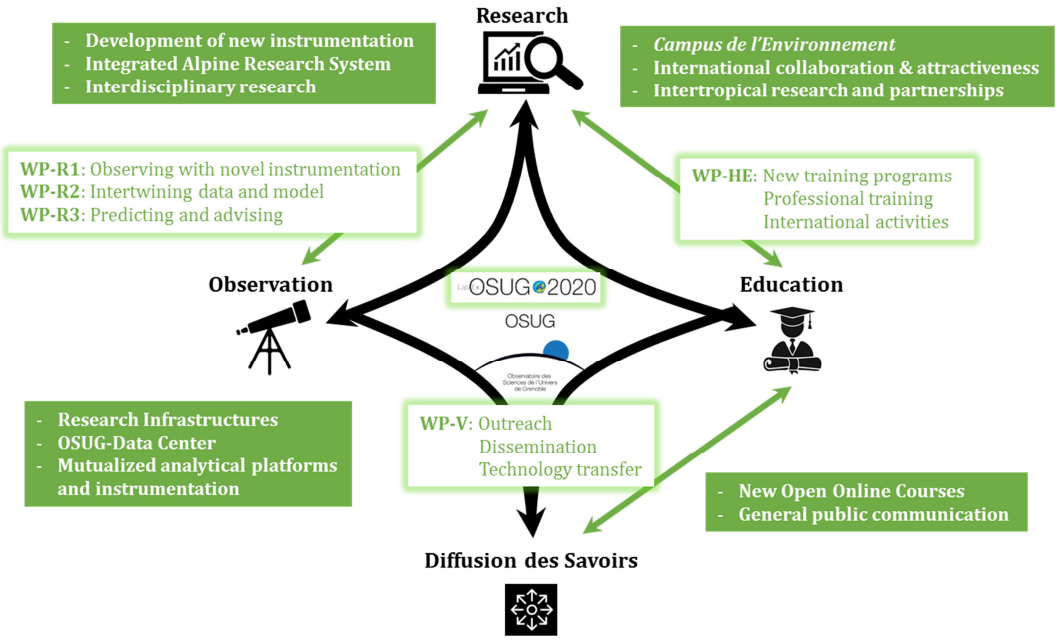


Figure 1: Schematic representation of the five OSUG@2020 work packages (green boxes), major achievements (filled green boxes), and the link to the OSUG missions (black).

The **main achievements** of OSUG@2020 (Fig. 1, green filled boxes) are fourfold: **structuring the OSUG community and its anchoring within the local, national, and international strategies**;

innovative and interdisciplinary research; **international attractiveness and visibility**; and **outreach towards different audiences**. The main outputs are described in the following section.

3.2 *MAIN PREVIOUS ACHIEVEMENTS*

OSUG@2020 has had an important impact in structuring efforts for the **involvement of local teams in research infrastructures (RI)**, for the development of the **OSUG Data Center (OSUG-DC)** concerning the treatment of data and images, data visualization and modeling, for the **mutual use of analytical platforms and instrumentation**, and for higher education via the ***Campus de l'Environnement***.

The OSUG community takes part in the **coordination of five RIs** and is involved in further five RIs in our scientific domains (Table 1). With ~11% of the overall budget, OSUG@2020 contributed to the development, use, and application of RIs and helped the OSUG community to **strengthen their observation strategy** and to **enhance their integration in international RIs**.

Table 1: OSUG involvement in RIs [a] related to the project.[1]

RI [b]	Internat. structure	National structure	National partners among project partner institutions	OSUG involvement [c]
IR	EPOS	RESIF	CNRS, IRD, IFSTTAR, UGA	Int. & nat. coord., obs., SNO
IR	E-LTER	OZCAR	CNRS, IRD, Irstea, Météo-France, IFSTTAR, UGA	Nat. coord., obs., SNO
		RZA	CNRS	Nat. coord., obs.
IR	AnaEE	FRANCE NATURA	CNRS, Irstea, UGA	Experimentation
TGIR	ICOS	ICOS-France	CNRS, IRD, Météo-France, UGA	Obs.
IR	ACTRIS	ACTRIS-France	CNRS, IRD, Météo-France, UGA	Int. & nat. coord., SNO
IR	ESO	INSTRUM-ESO	CNRS, UGA	Obs., SNO
TGIR	CFHT		CNRS	Nat. coord., obs., SNO
TGIR	IRAM		CNRS	Obs., SNO
TGIR	ESRF	FAME, FAME-UHD	CNRS	Experimentation

[a] Stratégie Nationale des Infrastructures de Recherche, Édition 2018, Ministère de l'Enseignement supérieur, de la Recherche et de l'Innovation, Paris.
[b] IR: Infrastructure de Recherche, TGIR: Très Grande Infrastructure de Recherche
[c] International & national coordination, observations, and Service National d'Observation SNO.

To increase the link between observation and research, OSUG@2020 invested ~8% of its budget in the development of **OSUG-DC**, which gathers **means and expertise in high-performance computing and modeling, data storage and sharing** via the computing platform Froggy, now integrated in the local high-performance computer center. For example, the Froggy platform played a crucial role to exploit data from the ROSETTA mission (see below). OSUG-DC is a crucial element for data dissemination at the international level and innovative research associated to our fields of expertise. This investment fostered the **hiring of new, highly-qualified permanent technical personnel**.

In addition to RIs and other *in situ* observations, the access to state-of-the-art analytical instruments for the determination of physical, chemical, and biological parameters in different matrices is a

[1] For a complete table with a list of all acronyms and SNOs see: www.osug.fr/IMG/pdf/table1.pdf

crucial issue for process understanding. Thus, **OSUG@2020 invested in equipment to advance and maintain its excellent position in geochemical analysis** and supported a **network of analytical and observational instrumentation and expertise**. For example, OSUG@2020 financed the acquisition of curved Germanium crystals to enhance the performance of the *French Absorption spectroscopy beamlines in Material and Environmental Science* (FAME, Table 1), which offers unique capacities for the analysis of environmental samples at unprecedented accuracy. All along the project and in particular **in 2017**, when **OSUG@2020 invested ~1 M€ in state-of-the-art equipment**, OSUG@2020 enhanced the capacity to apply and to exploit scientific instrumentation in field and laboratory experiments in extreme conditions and accessible to the entire OSUG community. For example, it contributed to the acquisition of an X-ray tomograph for cryospheric studies installed in a cold room and a geophysical network gathering hundred stand-alone seismic stations and wireless electric field sensors aiming at mapping and characterizing the subsurface of glaciers and volcanoes.

Table 2: Educational programs benefiting from the platform *Campus de l'Environnement* and from learning-by-doing supports

		Diploma	Speciality	Educational Departments
GRENOBLE	BSc	Sciences de la Terre	Physique, Sciences de la Terre Environnement, Mécanique; Sciences de la Terre et Environnement	PhITEM
		Métiers de la Protection et de la Gestion de l'Environnement	Prospection et Protection des Ressources Souterraines; Conception et Sureveillance des Systèmes Hydrauliques (CSH)	
		Physique	Centre d'Enseignement Supérieur & d'Initiation à la Recherche par l'Expérimentation	
		Agronomie	Eco-conseiller en production agricole	CH-BIO
		Mesures Physiques		IUT1
	MSc	Sciences de la Terre et des planètes, Environnement (STpE)	Géodynamique; Géoressources; Géorisques; Géophysique; Hydroressources; Earthquake, Engineering & Engineering Seismology; Atmosphères, Climat, Surfaces Continentales	PhITEM
		Physique	Astrophysique	
		Mécanique	Environmental Fluid Mechanics; Simulation et Instrumentation en Mécanique	
		Géographie, Aménagement, Environnement, Développement	Géographie, esPaces, Homme/Environnement, Ressources, systèmes; Géographie, Informations, Interfaces, Durabilité, EnvironnementS (GEOÏDES)	IUGA
		Biodiversité, Ecologie, Evolution	DYNAmique et MOdélisation de la biodiversité; Gestion de l'Environnement (GE)	CH-BIO
		Génie des Procédes	Génie des Procédés pour l'Environnement	
		Géotechnique et Génie Civil		Polytech Grenoble
		Ecole Nationale Supérieure de l'Energie, l'Eau et l'Environnement	Hydraulique ouvrages et environnement	G-INP
PALAISEAU		Energy Environment: Science Technology and Management		Ecole Polytechnique
LYON		Sciences de la Terre et des Planètes, Environnement	Terre et Planètes	ENS

Educational departments: **IUT1** Institut Universitaire de Technologie 1; **IUGA** Institut d'Urbanisme et de Géographie Alpine de Grenoble; **Polytech Grenoble** Ecole Polytechnique de l'Université Grenoble Alpes; **G-INP** Grenoble INP; ENS Ecole Normale Supérieure.

The educational platform ***Campus de l'Environnement*** had a major structuring impact in higher education. It includes **instruments for innovative field courses** and equipment with **dedicated software for data analysis** and treatment in fields ranging from Earth and Environmental Sciences to Astrophysics and Planetary Sciences.[2] OSUG@2020 funded the equipment and since 2013 also technical personnel. **65% of the platform is shared between different BSc and MSc programs** (Table 2) and **more than half of the used instrumentation is integrated in analytical platforms** for research ensuring formation actions with state-of-the-art equipment. 30% of the equipment of the *Campus de l'Environnement* (e.g. Planeterrella, Foucault pendulum, Coriolis platform, Lautaret snow platform) is regularly used in high-level schools like the European Research Course on Atmospheres (ERCA, see below) or in outreach activities. In 2016/2017, the quality and attractiveness of innovative teaching

[2] For the equipment of the *Campus de l'Environnement* and its use in UGA educational programs and at other institution of higher education see: www.osug.fr/IMG/pdf/campusdelenvironnement.pdf

actions of the *Campus de l'Environnement* was recognized for improving the professional training of students in the research fields of OSUG@2020 at local and other universities (Table 2) and allowed the **training of nearly 300 graduate students (~10% international students)**.

Concerning **main scientific achievements** (Fig. 1), OSUG@2020 had major transforming effects (i) on scientific progress related to WP-R1 to R3, (ii) on the development of new instrumentation for the observation of astronomical and terrestrial systems, (iii) for our comprehension of the integrated geodynamic, environmental, and ecological system of the Alps, and (iv) for interdisciplinary approaches to study the system Earth.

Through annual or biannual project calls OSUG@2020 has invested ~75% of its budget in projects concerning research and observation and 31 PhD theses (20 since 2015, 9 PhDs defended until March 2018) related to WP-R1 to R3. **Scientific progress** is reflected in more than **350 peer-reviewed publications**[3] acknowledging OSUG@2020 (> 260 since 2016, see Annexe publications). Here, we can only present three **selected highlights published in high-impact journals**. First, OSUG@2020 co-financed the upgrade of the laser ablation ICP-MS used to analyze komatiites, which contributed to a better **understanding of the conditions of the young Earth** implying a deep hydrated mantle reservoir.[4] Second, OSUG@2020 supported the analysis of ROSETTA data from the rendezvous with the Churyumov-Gerasimenko comet. Particularly, the computer platform Froggy was used for the treatment of radar data from the CONSERT instrument to reveal the **internal structure of the comet nucleus**.[5] Finally, OSUG@2020 supported the contribution of its scientists to a review of **snow and ice in the tropical Andes** by an international team of experts. The review demonstrated that despite uncertainties in the decline rate of snow and ice the **impact for several socio-economic sectors** are already visible and need to be considered for **comprehensive adaptation strategies**.[6]

Concerning the **development of new instrumentation**, OSUG@2020 played a major role in the initiation of the new instrument **SPIRou** (Spectropolarimètre Proche InfraRouge)[7] installed and tested for the first time in March 2018 at the CFHT. Due to the spectral resolution and coverage, the detector is optimized for the **detection and characterization of Earth-like planets** in the habitable zone around red dwarfs. In addition, OSUG@2020 contributed to the development of a novel **miniaturized static spectrometer** allowing the monitoring of methane and other greenhouse gases (GHGs) from space. This instrument will be used on board of a constellation of satellites developed at the Centre spatial universitaire de Grenoble (CSUG) in the frame of the H2020 project SCARBO (Space CARBon Observatory)[8] aiming at **monitoring GHGs with a high spatial and temporal resolution**. The innovative spectrometer technology is a major innovative element for the observation of further GHGs, reactive species, or ecological parameters in the infrared using airborne platforms like unmanned aerial vehicles or nano-satellites. As a result, OSUG will be a **key player** for the application of **infrared technology in the observation** of astronomical and terrestrial systems.

[3] See a full list of references here: www.osug.fr/IMG/pdf/listepublicationosug2020.pdf
[4] Sobolev et al., Nature 531, 628-632, doi.org/10.1038/nature17152, 2016.
[5] Kofman et al., Science 349, doi.org/10.1126/science.aab0639, 2015.
[6] Vuille et al., Earth-Sci. Rev. 176, 195-213, doi.org/10.1016/j.earscirev.2017.09.019, 2018.
[7] www.osug.fr/le-labex/actions-soutenues/recherche/Instrumentation/spirou.html
[8] https://cordis.europa.eu/project/rcn/212365_fr.html

In 2014, OSUG@2020 created the **Integrated Alpine Research System (IARS)**[9] through earmarked funding via annual project calls. The IARS enhanced our understanding and expertise of the **geophysical, environmental, and social system of the Alps** based on observations, *in situ* experiments, and modeling. The selected projects advanced our understanding of the functioning of various environmental compartments of the Alps as well as the impact of environmental changes on ecosystem services, tourism, and risks affecting the alpine communities.[10] For example, OSUG@2020 contributed to improve the predictions of the variation of species ranges in the Alps accounting for climate change and glacier retreat[11]. OSUG@2020 strongly supported the development of the regional atmospheric model MAR into a community model (mar.cnrs.fr), fostering dedicated applications in the Alps, other mountain areas, as well as polar regions. Since 23 of 24 projects involved multiple units or teams, the IARS enhanced **interdisciplinary research involving geophysical and environmental disciplines**.

Overall, OSUG@2020 strongly contributed to the **development of interdisciplinary research** within the OSUG community connecting **Geophysics, Environmental Science, and Ecology** via funding of research projects and PhD theses (e.g. the impact of black carbon on the air quality at European scale[12]). While around 25% of the supported research projects at the beginning of OSUG@2020 involved several disciplines represented by the different partners, this fraction increased to more than 50% in the years 2015 to 2017. As a result, the OSUG community constitutes now a **lively network of expertise and researchers** within a large spectrum of disciplines, and has been, therefore, involved in five so-called *Cross-disciplinary projects* (CDPs) selected by the IDEX UGA.[13] Overall, OSUG@2020 projects had a **leverage effect for more than 70 projects** funded by the IDEX UGA, the ANR, and the EU. Thus, OSUG@2020 **enhanced the research capacity** of the community and **broadened the spectrum of potential disciplinary and interdisciplinary issues** that can be addressed.

OSUG@2020 further favored **interdisciplinary research involving Social Sciences**. Such approaches were mostly developed in the frame of **PhD theses** (co)funded by OSUG@2020 and were mainly related to **risks associated with natural hazards**. For example, in the frame of a PhD project co-supervised by a US partner[14], a conceptual framework capturing the dynamic **interplay between flash flood hazards and social vulnerability** factors was developed. This work was based on a geospatial analysis of historic fatality situations, taking into account the victim's profiles, fatality circumstances, and the hydrometeorological context, and on a modeling approach able to map the

[9] www.osug.fr/le-labex/actions-soutenues/actions-d-envergure/integrated-alpine-research-system-iars/

[10] See for example Navel et al., J. Haz. Mat. 300, 538-545, doi.org/10.1016/j.jhazmat.2015.07.035, 2015. Spandre et al., Cold Reg. Sci. Technol., 125, 48-64, doi.org/10.1016/j.coldregions.2016.01.002, 2016. Chemel et al., Atmos. Environ. 128, 208-215, doi.org/10.1016/j.atmosenv.2015.12.058, 2016. Calas et al., Atmos. Chem. Phys. 18, 7863–7875, doi.org/10.5194/acp-18-7863-2018, 2018.

[11] Carlson et al., Div. Distrib. 20, 1379-1391, doi.org/10.1111/ddi.12238, 2014.

[12] Zanatta et al., Atmos. Environ. 145, 346–364, doi.org/10.1016/j.atmosenv.2016.09.035, 2016.

[13] See risk.univ-grenoble-alpes.fr; mobilair.univ-grenoble-alpes.fr; trajectories.univ-grenoble-alpes.fr; origin-life.univ-grenoble-alpes.fr; data-institute.univ-grenoble-alpes.fr

[14] G. Terti et al., Nat. Hazards 79, 1481-1497, doi.org/10.1007/s11069-015-1910-8, 2015. G. Terti et al., Bull. Amer. Meteor. Soc. 98, 333-345, doi.org/10.1175/BAMS-D-15-00276.1, 2016. G. Terti et al., Risk Analysis, doi.org/10.1111/risa.12921, 2017.

dynamic risk exposure. Other interdisciplinary PhD theses[15] addressed the dynamics of **rock-fall in alpine valleys** or the characterization of **landslides in Peru and their impact on the concerned societies**. So far, such PhD theses involving Social Sciences resulted in **more than 10 peer-reviewed publications**.

To better prepare the students for their future professional perspectives, OSUG@2020 also contributed to the **promotion of interdisciplinary training** within the curricula redesigned in 2016. OSUG@2020 supported actions like the **consolidation of the intervention of social scientists** in teaching initiatives by sharing training on water management between BScPro CSH (PhITEM) and Economie et Gestion de l'Eau et des ressources (UFR Economie), by **mutualizing courses on the concept of risks** between MSc GEOÏDES (IUGA) and Géorisques (PhITEM), by **teaching environmental law** in MSc GE (CH-BIO), and by supporting the recurring *Water & Society Integrated Studies* high-level school.

Due to OSUG@2020 funding, the OSUG community enhanced its **international visibility and attractiveness**. Co-funding of research and teaching projects has **more than doubled the available funding** since a total of ~8.3 Mio € from OSUG@2020 mobilized additional 10.3 Mio €. For example, the project SPIRou received 80 k€ and generated (inter)national co-funding of more than 2 M€. Overall, **private co-funding** provided ~440 k€, while **international co-funding** contributed more than 2.7 M€. Over 90% of the projects delivered **scientific reports, publicly available** on the project web page (www.osug.fr/labex-osug-2020/). The excellent international integration is mirrored by the fraction of the publications linked to the project (>70%) with **international co-authors**. The involvement in RIs (Table 1) also has a strong impact on the visibility due to their national and international construction. UGA is **ranked globally between #18 and #100** in the recent university rankings Shanghaï, Taïwan, US News & World report, and QS World University in fields like **Geoscience, Earth Sciences, Physics & Astronomy, Space Science, and Environment & Ecology**. Recognizing the dynamic research and attractiveness, UGA, USMB, CNRS, IRD, Irstea, Météo-France hired **58 permanent researchers since 2011** (21 since 2015) for the participating units and teams. Moreover, **four *Make our Planet great again* projects** led by international researchers as well as **eleven ERC projects** (five since 2016) have been and are conducted in the units IGE, IPAG, ISTerre, LECA, and Irstea.

OSUG@2020 support aimed at increasing international collaboration through two types of **PhD student exchanges**[16]: i) participation of local PhD students in high-level schools addressing their thesis topic and ii) accommodation of PhD students at OSUG@2020 partners to acquire innovative methods, concepts, and technologies. Since 2015, these actions led to **60 PhD students trained in 18 different countries**, allowing the enhancement of their own network, the advancement of their doctoral research project, and the scientific gain for OSUG. Moreover, OSUG@2020 favored international actions at the MSc level by trans-European university trainings with mixed nationalities of students and teachers, field trainings abroad, and confronting scientific experience. OSUG@2020 has further (co)funded **80 international events** (48 since 2015, 28% workshops, 22% seminars, 50% high-level schools; more than 40% interdisciplinary events). ~1800 experts (~55% international) and ~2800 participants (~400 national and ~1000 international Master and PhD students) took part in

[15] For a full list of (co-)funded thesis topics see: www.osug.fr/le-labex/actions-soutenues/Theses/
[16] For a map of countries for student exchanges see www.osug.fr/IMG/pdf/mappingphdtrainings.pdf

these events. One major action is the annual **European Research Course on Atmospheres (ERCA)**, for which OSUG@2020 provided support for international speakers and participants (especially students from inter-tropical countries) and allowed up-to-date trainings using the *Campus de l'Environnement*. Between 2011 and 2018 nearly 300 participants (~90% international students) from ~50 countries and ~50 international experts participated in this renowned school.

Partnerships with inter-tropical and Mediterranean countries were particularly favored due to the long-lasting scientific cooperation of OSUG laboratories in particular concerning crucial issues like **seismic hazards and risks and water cycle vulnerabilities**. At the MSc level, OSUG@2020 funded **five international students per year (South America, Asian and African continents)** to attend one of the MSc programs in the scientific domains of OSUG@2020. Numerous projects in about **23 countries in Africa, in South and Southeast Asia, and South America** were supported including the exchange of PhD students and academics and exchanges for field schools[17]. Since 2015, **twelve training actions** were supported to secure exchanges with teachers from **Niger, Benin, Peru, Ecuador, Bolivia, Lebanon, and Vietnam**. In Benin, Bolivia, and Vietnam several hydro-geophysical training courses supported six PhDs, master students and teachers leading to **perennial collaboration** in Hydrology and OSUG RIs. OSUG@2020 supported the cooperation with Lebanese universities and the Agence universitaire de Francophonie contributing to the exchange of 14 students and six PhDs resulting in five publications. This collaboration fostered the recent **creation of an MSc co-graduation (UGA & University Lebanese) in Geosciences**. OSUG@2020 strengthened several **partnerships with Lebanon, Vietnam, Benin, and the Ivory Coast**, for which the OSUG community proposes CNRS- and IRD-supported long-term actions like *Laboratoire International Associé* (LIA) and *Laboratoire Mixte International* (LMI) that are currently under evaluation.

OSUG@2020 supported the OSUG **communication service via direct funding and human resources** with 4% of its budget. This service conducted a series of actions creating **new modes of communication** within the OSUG community as well as with different audiences. Internal exchanges were strongly improved via the distribution of monthly newsletters and the annual *Journée de l'Observatoire* for all OSUG members with official, scientific, and social events. External communication was enhanced via the **web page, the presence in social media, and the publication of ~300 news including 116 press releases** (180 news and 64 press releases since 2015) concerning important scientific findings and events. Furthermore, OSUG@2020 **enhanced the attractiveness of dissemination actions** like school class visits, stands during the *Fête de la science*, telescope nights, and geological hikes by better coordination and by providing equipment from the *Campus de l'Environnement*. Two **Massive Open Online Courses** (MOOCs): *Des Rivières et des Hommes* and *À la recherche d'autres planètes habitables* supported by OSUG@2020 reached out to >11000 registered participants from >150 countries resulting in >1100 certificates of achievement. OSUG@2020 helped developing the **film festival *Rencontres Montagnes et Sciences***[18] from a single evening event into a full tour with presentations in Grenoble, Valence, Clermont-Ferrand, Lyon, and surrounding places. The communication service and further OSUG members are involved in the preparation of the *Etablissement public de coopération culturelle* (EPCC), which will implement the **local exhibition**

[17] For a map of concerned countries in scientific programs with inter-tropical countries see www.osug.fr/IMG/pdf/mappinginter-tropicalcountries.pdf

[18] www.osug.fr/grand-public/les-evenements-annuels/Rencontres-Montagnes-et-Sciences.html

center *Moulins de Villancourt* dedicated to Geosciences, Environmental and Planetary Science, and Astrophysics.

Valorization actions of OSUG@2020 concerned the **transfer of technology** and the **advising of local stakeholders**. OSUG@2020 contributed to the development of **proofs of concept** or **patents in civil engineering** (e.g. concrete and road stability, rock deformation, water decontamination, pollutant monitoring). OSUG@2020 funded **public advice** for example via web-based services like sismalp.osug.fr giving **access to the detailed seismicity of the western Alps** recorded by the RI RESIF for local and regional authorities and civil protection agencies or via the regional Ouranos platform by workshops intended for public-sector actors and devoted to **data collection in mountain regions on climate change** and its impact. In collaboration with local authorities, OSUG@2020 supported geophysical measurements for the **monitoring and risk assessment of the Taconnaz glacier** threatening communities in the Chamonix-Mont Blanc area.

In conclusion, OSUG@2020 **strengthened the astrophysical, geoscientific, ecological and environmental community**, which has strongly evolved since the beginning of the project. This multi-disciplinary community contributes to and benefits from i) **national and international RIs**, ii) locally **shared analytical platforms and instrumentation** and iii) a **dedicated IT and data center**. It has also conducted **novel interdisciplinary research** highly recognized in the international community. In addition, OSUG@2020 has **brought together research, observation, and education** highlighted by the *Campus de l'Environnement* and by **strengthening international partnerships**. Strong communication actions helped to create a tightly linked community undertaking **attractive outreach activities** and providing **policy-relevant information and advice**.

4 PROJECT DESCRIPTION AND EXPECTED IMPACT

4.1 SCIENTIFIC SCOPE AND CONTENTS OF THE PROJECT FOR THE NEXT FINANCING PERIOD, EXPECTED IMPACT

The prolongation is based on the structural, scientific, higher education, and outreach achievements of OSUG@2020, which will be strengthened further to complete major advancements in our domain. Nevertheless, we identified the need to define an **attractive and pressing scientific topic** leading to an even stronger mobilization and cohesion of our community for more focused actions and activities leading to an enhanced visibility on a local, national, and international scale. Based on the input of the OSUG community, the analysis of our forces and strengths, and an assessment of knowledge gaps in our scientific fields, we identified ***Habitability in changing worlds*** as the central theme for the prolongation period to guide future actions and activities of OSUG@2020. Habitability is characterized by the ensemble of conditions to be fulfilled for any form of life. Habitability is linked to a location (= a habitat) exhibiting *a collection of resources and environmental conditions (abiotic and biotic) that determine the presence, survival, and reproduction of a population*.[19] In this project we will use the concept of habitability to study a range of locations based on observations, experimentations, and modeling. The studied objects will range from **celestial bodies** (stars, planetary disks, exoplanets to planets) **to terrestrial environments**, where basic conditions for

[19] Aarts et al., J. Anim. Ecol. 82, 1135-1145, doi.org/10.1111/1365-2656.12061, 2013.

habitability up to complex requirements for human societies will be examined. OSUG@2020 contributes to the scientific basis for reaching the **UN sustainable development goals** SDG 6 (Water), 7 (Energy), 9 (Habitat), 11 (City), 13 (Climate action), and 17 (Partnership). The project was motivated by and profits from CDPs with strong OSUG contributions[11]: *Data Institute*; *Trajectories for alpine socio-ecosystems in a changing world*; *Origin of life*; *Mobility and improvement of air quality*; and *Managing risk for a more resilient world*.

The project will support the integration of existing or innovative monitoring activities at OSUG into international networks. It also offers the opportunity **exploiting RIs in a multidisciplinary manner**[20] tackling key challenges for the project. For example, we will seize opportunities to enable the integration and co-location of terrestrial infrastructures responding to **recommendations of the EU for the development of RI networks**. Our best example of a proof-tested multi-scalar deployment of RIs is the highly instrumented master site located at Col du Lautaret in the Alps. There, on-going long-term research projects on social-ecological systems supported by E-LTER are benefitting from SAJF infrastructures for small scale experimentations supported by AnaEE and from an emerging high-elevation site for the monitoring of GHGs supported by ICOS-France. The **complementarity and co-location** of these RIs will allow us to tackle key research question at the crossroad between Geosciences, Ecology and Social Sciences such as the relationship between snow cover dynamics, plant functional diversity, and ecosystem services of mountain grasslands relevant for certain aspects of terrestrial habitability. Strong synergies will also be developed concerning **sensor technology** and the design of new sensor networks to better probe mountain environments. The **interoperability** of these RIs also translates into common data treatment, formatting, and quality-control and a better integration of empirical data into modeling approaches. Examples include an improved implementation of regional climate scenarios into biodiversity models, the quantification of ecosystem services, or the monitoring and modeling of the biogeochemical nitrogen cycle at the watershed scale with specific questions related to seasonally snow-covered ecosystems.

Since physical, chemical, and optical analytical equipment and expertise will be instrumental to reach the project goals, we will continue investing in **state-of-the-art instruments for shared analytical platforms**. With these platforms we also intend to contribute to an emerging national RI consisting in a network of analytical capacities and expertise in geochemistry (*Réseau Géochimique et Expérimental Français*, RéGEF).

Remote sensing observations provide a steadily growing flux of data with an increasing temporal and spatial coverage and an augmenting number and quality of derived products. Data from CNES/ESA/NASA satellites (e.g. SWOT for water resources) and solar system probes (e.g. GAIA or soon MARS2020, EXOMARS, JWST) are needed to fully **exploit observations obtained with ground-based RIs**. We will further continue using innovative data from **unmanned aerial vehicles** and in the future from **nano-satellites** providing an enhanced space and time coverage at lower costs compared to standard satellites. The project will benefit from and contribute to major actions in the field of Earth observation and prediction particularly related to the European program *Copernicus*.

OSUG-DC is a further major element to connect RIs, *in situ* measurements, as well as remote sensing observation. OSUG-DC ensures the **sustainability and accessibility of project data** and fosters data sharing and openness policies impacting data harmonization, sharing practices, and cultures across

[20] Kulmala, Nature 353, 21-23, doi.org/10.1038/d41586-017-08967-y, 2018.

the domains. Relevant IT infrastructures concerning storage, data flow, and computational needs as well as human resources will be put in place. The use and application of **advanced mathematical methods** related to deep learning and artificial intelligence will be supported for the analysis of model output as well as large data sets generated by observations.

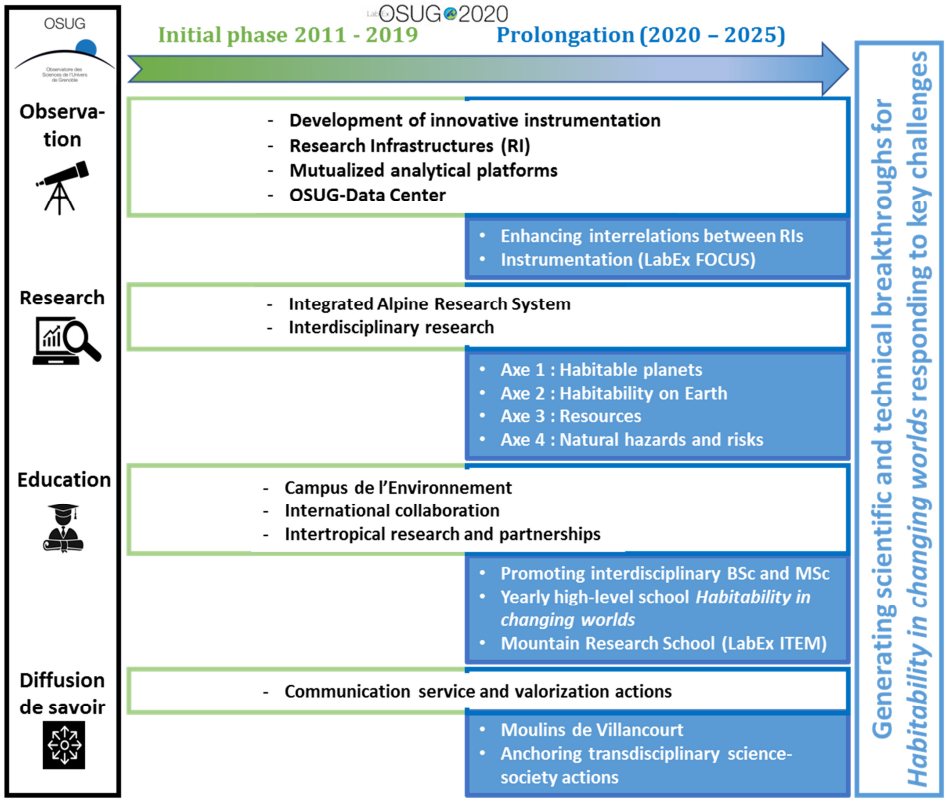


Figure 2: Schematic representation of the link between the initial and the prolongation period, the major achievements, and the main objectives.

The project addresses four **scientific key challenges** in the following four scientific axes: **1. What makes and keeps planets habitable? 2. How can we integrate the multiple facets of habitability on Earth? 3. How is habitability maintained with limited resources? 4. How do natural hazards and associated risks contest habitability?** Physicists, planetary scientists, geologists, glaciologists, geophysicists, hydrologists, ecologists, and social scientists will work together in four scientific axes to address these challenges and to realize **scientific and technical breakthroughs**.

Axe 1: What makes and keeps planets habitable?

The detection of 3500 extrasolar planets, a few of them potentially habitable, has revealed the diversity of planetary systems and revolutionized our ideas on planet formation and evolution. Identifying habitable Earth-like planets and searching for biomarkers in their atmospheres is one of the main challenges of our century. We will study the **origin and formation of habitable planets**, the astrophysical and planetary parameters, which maintain habitability on Earth (and potentially on other planets), and the stability of the terrestrial atmosphere and climate. We aim at understanding how unique our own Earth is and at assessing whether life could exist elsewhere in the universe.

For the planetary formation, we will study small bodies (e.g. asteroids, comets), which recorded chronological, dynamical, and chemical conditions at play during the formation of the solar system

from the interstellar medium to young stars and disks. Beyond the solar system, star and disk formation mechanisms produced a wide variety of planetary bodies. Infrared (SPIRou/JWST) and submillimeter (ALMA/NOEMA) observations combined with physical modeling will help constrain disc composition and structure, whose complexity is a telltale trace of ongoing planetary formation mechanisms. We will carry out statistically robust observations throughout thousands of nearby stars to determine the frequency of **rocky planets in the habitable zone**. We are a major partner for the upgrade of SPHERE with a high-spectral resolution capability before 2022 to **characterize the atmosphere of the closest habitable exoplanet** Proxima b[21] and to search for biomarkers.

The architecture of the **solar system** with four planets close to the Sun and four giant planets played a key role during the formation of our planet ensuring the terrestrial orbital and, thus, **climatic stability**. We will examine the radial velocity, transit, and direct imaging data from **extrasolar systems** to understand their architectures and orbital stability. Earth gravity and its magnetic field have preserved its atmosphere from escaping to space. We will investigate whether similar shielding can exist for different types of exoplanets. The **dynamics of the planetary core** are paramount to understand and predict the strength, morphology, and decline of the magnetic fields. We will combine our expertise on the formation of Earth's magnetic field with observed parameters for the **mass, age, and composition of exoplanets** to assess their ability to **sustain a dense atmosphere**.

Life on Earth has been resilient to highly changing climatic conditions and to sporadic catastrophic events triggered by volcanism and asteroid collisions. We will study **natural** (e.g. orbital forcing) **and anthropogenic factors impacting climate variability** at time scales ranging from 100 kyr cycles to recent centennial and millennial climatic variability based on an array of records at the poles and in the tropics. We will focus on **cryospheric and marine processes**, which have a strong impact on terrestrial habitability linked for example to the sea level and which may be important components for the climate stability of exoplanets. We will compare the role of tectonics and biogeochemical cycles for **climate stability on Earth and Mars** based on the MARS 2020 mission, which will address issues like catastrophic climate changes, habitability, and life emergence on our neighbor planet.

Axe 1 involves the RIs ESO (ALMA, SPHERE), CFHT (SPIRou), IRAM (NOEMA, NIKA2), and ICOS. The challenges in modeling on timescales allowing life to emerge are threefold: dynamical and/or chemical modeling of (i) the formation of stars, disks, and planets, (ii) the dynamical stability of planets in the habitable zone, and (iii) the molecular complexity in the atmosphere of exoplanets. Geo-dynamo and climate modeling related to the persistence and evolution of the atmosphere of planets will enable interdisciplinary breakthroughs. Axe 1 aims at reinforcing interdisciplinary research involving astrophysics, planetary science, geology, climate science, and ecology.

Axe 2. How can we integrate the multiple facets of habitability on Earth?

Properties of different compartments ranging from the deep Earth to the atmosphere and through a wide range of scales (e.g. from local to regional to global scales, from seconds to millions of years, and from genes to ecosystems) are intimately linked to terrestrial habitability. [22] The **critical zone (CZ)** is a place of a variety of life forms and living organism as well as an important interface for major

[21] Lovis et al., A&A 599, 16, doi.org/10.1051/0004-6361/201629682, 2017.
[22] e.g. Katling & Castling, Atmospheric evolution on inhabited and lifeless worlds, Cambridge University Press, ISBN 978-0-521-84412-3, 2017. Guillot & Hattori, Elements 9, 95–98, doi.org/10.2113/gselements.9.2.95, 2013.

compartments. Thus, the main objective is contributing to a comprehensive **understanding of the CZ and linked compartments** based on a tight coupling of observations, experiments, and models. Related to the SDGs, we will focus on the interrelations and their associated time and space scales of the impact of the CZ and the compartments on the habitability on Earth. In particular, we will examine **future trajectories of the compartments** influenced by global change and anthropogenic activities. We will **focus on inter-tropical regions**, where the rapid population growth and the (unregulated) industrial development increase the risk of ecosystems contamination, and on **mountainous regions**, where the increasing urbanization and atmospheric pollution from the valleys interplay with a shrinking cryosphere, land use changes, and increasing human (touristic) activities.

More specifically, for the **deep Earth's dynamics**, we will characterize transfers of fluids and the stability of magmatic reservoirs in active settings such as volcanic and hydrothermal systems through the combination of time-resolved high-resolution seismic data (velocity and attenuation) and fluid-sensitive magneto-telluric methods. Long-term trends of the interactions between the **cryosphere** and other compartments of the Earth system will be investigated by the integration of several RIs. New geochemical tracers and proxies including isotopes will be developed and applied together with ecological (environmental genomics, biomarkers) and climate proxies. Since biodiversity is influenced by both ancient and current physical processes (e.g. plate tectonics, land use changes, climate change) together with biotic processes, we will use the recorded **solid-Earth dynamics to understand the origin of biodiversity** and the rate of diversification in the Alps using novel phylogenetic tools and benefiting from geophysical observations unraveling complex transient deformations of the lithosphere and erosion processes. As far as the **interrelations between CZ processes and human activities** are concerned, we will quantify the mass transfer, the transformation and the (bio)accumulation of pollutants, engineered nanoparticles, and emerging contaminants in different compartments to analyze **tipping points of ecosystems** and quality issues for the CZ. A variety of natural archives (e.g. peat, sediments, ice cores) will be studied to explore past human activities. Environmental solid particles like cryptocrystalline or amorphous nanoparticles and their surface interactions with environmental matrices (biotic and abiotic) will be examined by combining innovative characterization techniques (in house and synchrotron based) and molecular simulations.

Axe 2 aims at bringing closer the RIs EPOS, E-LTER, AnaEE, ICOS, ACTRIS, and ESRF (FAME). It also requires a better coordination of geochemistry and sequencing[23] platforms. Exploiting observations and experiments, numerical models based on the geophysical characterization of subsurface media and coupling meteorology, hydrogeology, and mass transfer (atmosphere, water, sediments, biotic and abiotic contaminants) will be developed to study processes in regions strongly affected by global changes. Developments of integrated models of the CZ taking into account anthropogenic activities and social dynamics will be a key issue for axe 2.

Axe 3. How is habitability maintained with limited resources?

Understanding the interaction of the exploitation and use of resources, their quality and limitations for the environment taking into account conditions and quality of life as well as social and economic aspects are important for long-term terrestrial habitability. We will apply our multidisciplinary expertise and knowledge in particular in mountainous and inter-tropical regions to **characterize and**

[23] Taberlet et al., Environmental DNA: For Biodiversity Research and Monitoring, Oxford University Press, ISBN 9780198767220, 2018.

quantify traditional and new natural resources (e.g. water, biodiversity, minerals, trace metals, renewable energy) and their **sustainable exploitation**. We will also contribute to the characterization of water resources in the solar system, which are crucial for future human exploration and deep space navigation.

While the impact of changes in precipitation regimes and land use on terrestrial hydrological regimes has been studied, the attribution is a major challenge for predicting future **changes in the socio-eco-hydrological system**. To tackle this issue, we will study the water transfer from the atmosphere to aquifers and vice versa and their associated time and space scales and analyze their response to land use changes and anthropogenic pressure. We will identify potential tipping points concerning abrupt or radical changes that may occur as a result of the impact of ongoing climate change and changes in surface conditions.[24] For the **evaluation of ecosystem services** in a context of global changes, we will develop interdisciplinary long-term social-ecological research networks in partnership with local populations, territorial managers, and policy-makers with a special **focus on mountain territories**. We will analyze the **properties of different natural resources** (e.g. concentrated vs. diffuse, regular vs. irregular, multiple physical, chemical, and environmental states), which influence the **use of resources and the elaboration of related policies**.

The vulnerability of natural resources in terms of quality and quantity associated with the increasing demands will be explored as well as their consequences on habitability conditions. We will work on **mitigation and adaptation** strategies in case of shortages of natural resources including **eco-engineering methods**. We will contribute to strategies for the optimized management of subsurface systems **solving water-energy issues** at local, regional, and global scales. We will further participate in an active environmental and societal strategy for **sustainably harnessing mineral resources** using not only cutting-edge exploration techniques, but also accounting for the potential social conflicts and environmental constraints on production. The **'green' paradoxes** (e.g. global gains vs. local impacts) will be analyzed and the emergence of new actors induced by the appetite for new resources and the rising interactions between these processes and the environment at different scales will be studied. We will further examine how renewable energies and their associated engineering solutions will impact and interact with other related resources (i.e. land, water, biodiversity).

Axe 3 involves the RIs EPOS, E-LTER, AnaEE, and ESRF (FAME). Besides the interactions within these RI, the main challenges will be to share interdisciplinary approaches currently developed in each domain associated with specific resources and to strengthen OSUG knowledge and expertise on the nexus between water, energy, environment, and climate. [25] Axe 3 will contribute and reinforce the IARS and the link with the territorial actors and local stakeholders.

Axe 4. How do natural hazards and associated risks contest habitability?

The OSUG community possesses a long-standing and multidisciplinary expertise on natural risk assessments concerning earthquakes, geo-resources, landslides, ice and debris flows, flooding, and snow avalanches mainly occurring in mountainous regions. The close ties between OSUG scientists, stakeholders, and decision makers grouped in the Alpine Center for Natural Hazards and Risks

[24] Lenton et al., PNAS 105, 1786–1793, doi.org/10.1073/pnas.0705414105, 2008.
[25] e.g. Hamiche et al., Renew.Sustain.Energy Rev. 65, 319-331, doi.org/10.1016/j.rser.2016.07.020, 2016.

Prevention (PARN) for three decades has strongly fostered the development of interdisciplinary research towards a better understanding of interrelations between natural, technological, and human systems. In this context, our objectives are threefold: i) improving the **knowledge of physical processes of natural hazards and the cascade of hazards**, ii) assessing the **vulnerability and capacity of the environment to withstand extreme events** and forecasting their impact and consequences for urbanized and industrialized areas, and iii) developing models for decision-makers for the **adaptation of exposed areas and infrastructures** and the **improvement of their resilience**.

Through data-driven methods (e.g. deep learning, ensemble-based data assimilation systems) we will improve our understanding of physical processes responsible for natural hazards in relation to **climate change and urbanization** for a better forecast of uncertainties related to hazards. Inspired by models developed for avalanche hazard forecasting, innovative models (e.g. snowmelt floods, rain-on-snow events, rate of seismicity) will be developed in full synergy with observations and experiments addressing **operational forecasting and short- and long-term predictions**. In addition to terrestrial hazards, emerging activities concerning **space weather and geo-cruisers** will be developed. We will investigate the space weather related to the impact of solar activity on the Earth's space environment with **implications for telecommunication, global positioning, energy, and transport**. Potential **hazardous near-Earth asteroids** and planetary protection will be studied by systematic surveys and monitoring from ground-based or space-borne observatories.

As far as risks are concerned, we will assess the **physical, systemic, and human vulnerability** and their evolution for different territories through both systematic surveys (i.e. historical archives and paleo-records) and remote sensing techniques. We aim at developing **innovative risk assessment methods** combining probabilistic hazard models and vulnerability relationships to evaluate different risk metrics for the design of **optimal mitigation strategies and decision-making**. We will study the impact of global change and the urbanization on the risk evolution through stochastic and high-resolution numerical modeling, generating an added-value for the evaluation of decision making and prevention strategies to reduce risk and improve the resilience.

Axe 4 involves the RIs EPOS and E-LTER in strong interactions with laboratory experiments and novel data acquisition systems such as remote sensing, ground lidar, and ground photogrammetry. The integration of socio-economic aspects in coupled models constitutes a major challenge. While new tools to assess environmental risks will be developed, the prediction of numerous hazards still remains an unresolved issue. Empirical, numerical, and stochastic modeling will contribute to this key issue. Axe 4 will strongly reinforce the IARS.

To reinforce the integration of OSUG@2020 at the local scale, further cooperation concerning the development of detectors and mountains and societies are envisaged with the two local LabEx FOCUS (Focal Plane Array for Universe Sensing) and ITEM (Innovation and Mountain Territories).

The **development of new instrumentation** dedicated to *in situ*, airborne or space instrumentation observations will be addressed in collaboration with the **LabEx FOCUS**, which deals with the development of innovative optical detectors from the visible to millimeter wavelength including the infrared. The miniature and highly sensitive instruments realized by FOCUS will be essential to obtain physical, chemical, and biological properties of the atmosphere and the Earth surface.

Interdisciplinary research and the IARS will be developed further within the new ***Mountain Research School* (MRS)** shared with **ITEM**. This school located at the **Alpine Field Station of Lautaret** (SAJF, see

3.2) will be an *altitude camp* for events to strengthen the link between Social and Natural Sciences with a **series of actions**: (i) coupled theses for at least two linked subjects, which are studied in parallel with a natural and a social science approach; (ii) interdisciplinary doctoral committees for all PhD thesis related to mountain studies of axes 3 and 4; (iii) at least two cycles of the high-level school *Habitability in changing worlds* (see 2.2); and (iv) the training of mountain stakeholders. Since in complex mountain regions, the high variability in topography, large gradients, and the difficult access are challenging to overcome with traditional methods, the **public participation in scientific research** (i.e. Sentinelles des Alpes) offers new possibilities to generate unprecedented observational time series. The MRS will support innovative methods like citizen science or other participative methods.[26] It will enhance such actions using the technical platform and the scientific reputation of the SAJF reaching out to **~15000 international visitors** annually.

4.2 RESEARCH-LEARNING INTERFACE AND EXPECTED IMPACT

Based on the previous achievements, the project will further enhance the culture of innovation and carry on the development of **interdisciplinary educational programs** with a high **international attractiveness** to strengthen the students' level of excellence in the scientific domains of OSUG.

In the context of the renewal of local BSc & MSc programs taking place in 2020, we will co-develop and support programs relying on **novel educational actions** (e.g. the confrontation of experience between experts-students; the creation of courses/projects mixing MSc & PhD students). Moreover, we will be proactive in the development of interdisciplinary courses to deepen learning-by-experience methods and to develop the creativity of future researchers or professionals. For example, the **teaching of Ecology, Social and Earth Sciences in a fully integrated program dedicated to mountain or extreme environments** will be promoted. We will enhance attractiveness by promoting international expert engagements in BSc & MSc programs and experience abroad by further developing **international partnerships and double MSc diploma**. All actions are expected to increase the proportion of international students and to facilitate the job placement of the students.

We will continue supporting the ***Campus de l'Environnement*** by providing up-to-date equipment in hydrology, geophysics, atmospheric sciences. Enhancing the **integration of RIs into training activities** at different levels will be our main focus and challenge. For example, E-LTER will be integrated into appropriate professional education programs covering hydrological, hydro-geophysical and socio-ecosystem sciences or AnaEE (via SAJF) will provide unique facilities for learning-by-doing projects dedicated to mountains, climate, environment and ecology.

The project will continue to boost **international partnerships and bilateral PhDs**, in particular for students from our **inter-tropical partners**. Moreover, the integration of students beyond their training will also be supported by continuing or initiating efforts with student associations, with **alumni** networks, with forums to discuss career development, etc. These actions will be performed in connection with UGA-IDEX actions in higher education.

Concerning high-level schools we intend to contribute to **innovative and interdisciplinary actions for ERCA**. Based on the experience of our community, a **new yearly high-level school** will be created to

[26] Riesch & Potter, Public Understanding Sci. 23, 107–120, doi.org/10.1177/0963662513497324, 2014.

strengthen the **international knowledge transfer and international networking among young researchers** related to the project. It will: (i) develop advanced tools for the evaluation of habitability, (ii) integrate the dynamics of changes, (iii) provide a multidisciplinary basis on the notion of 'environment' (abiotic, biotic, and societal), and (iv) raise awareness on the notion of 'resources'. **Cycles of themes** will be constructed and at least two issues will be linked to the MRS (see 2.1): e.g. physical and chemical properties of environments (celestial bodies, Earth); abiotic and biotic dynamic interactions; dynamic of changes in environments; resource quality; societal vulnerability and prediction of risks; habitability in mountain regions. To our knowledge, such a high-level school does currently not exist. A motivated **interdisciplinary organizing committee** with G. Picard (Prof., IGE, gp.snow-physics.science), P. Beck (Maître de Conferences, IPAG, ipag.osug.fr/~beckp/), and F. Boucher (Maître de Conferences, LECA, sites.google.com/site/floriaboucher/) already exists.

4.3 VALORIZATION STRATEGY OF THE PROJECT AND *SOCIO-ECONOMIC IMPACT*

For an improved **coordination of the dissemination and valorization** activities a **Chargé de mission** will be nominated. We will continue to strengthen the dissemination our scientific findings to a wide audience ranging from **school actions to scientific conferences**. Some of the outreach actions will be integrated in the future EPCC, which is under construction between local institutions e.g., UGA, Grenoble Alpes Métropole, *Centre de Culture Scientifique Technique et Industrielle-La Casemate*,…). The involvement in the **exhibition center *Moulins de Villancourt*** close to Grenoble (initiated by OSUG@2020) will be pursued by the definition of the scientific content, for which OSUG is responsible, by the training of the animators, and by collaborating with communication experts to showcase ongoing research in our units. We will focus on *Special feature stories* covering two themes per year addressing different public audiences through **pedagogical booklets** dedicated to teaching actions (scholar, neophyte, aficionado), through local and national media, through local exhibition posters (on display in e.g. OSUG laboratories, the MRS, the EPCC partners) and through specialized events (seminars, multi-sectoral round-tables, visits of infrastructures for a broad audience). Moreover, we will engage in the **training of mountain stakeholders** (mountain guides, …) and humanitarians (association *Humacoop*) for actions related to the topics of the four scientific axes.

To enhance our interactions with local non-academic actors (e.g. Grenoble Alpes Métropole; other local authorities in the addressed regions/countries) and stakeholders (e.g. national and regional parks; NGOs) we will elicit their needs and elaborate the **co-construction of transdisciplinary actions** (e.g. on the adaptation of territories to global change, training related to the exploitation of environmental data and satellite products and their limits). Such actions are **based on the experience of the OSUG community** acquired with the PARN, the Ouranos science-society platform of the region Auvergne-Rhône-Alpes, and in CDP projects. For example, Ouranos and Kalideos-Alps joined their efforts to create a regional animation center (*Animation Régionale Theia Alpes*) for data bases promoting the use of satellite data by end-users and getting feedback on their needs.

2.4 INTEGRATION SCIENTIFIQUE ET PEDAGOGIQUE A LA STRATEGIE DE L'ETABLISSEMENT PORTEUR ET DES ETABLISSEMENTS PARTENAIRES

The scientific program and the project objectives are coherent with the **research and observation strategy and programs of the national partner organizations** (see Lettres d'Appreciation). Moreover, the project is fully in line with the **objectives and strategy of the Idex UGA and its participating**

universities concerning **excellence, innovation, and interdisciplinary approaches** in research, teaching, and valorization. OSUG members actively participate in the management, implementation, and execution of major entities, actions, and activities of the Idex UGA as well as of our partner institutions. Furthermore, links to UGA structures like **CSUG** will be reinforced, which is a key player in the development of **scientific payloads for nanosatellites**. Support by OSUG@2020 has been essential in the early phase of the miniaturization of a spectro-imager. The further development of **innovative and heavily miniaturized detectors and instruments** is currently carried out in cooperation with the Grenoble-based space industry and we will reinforce our collaboration regarding the application of such novel tools and miniaturized instrumentation for Earth observations since OSUG members actively participate in the CSUG strategy.

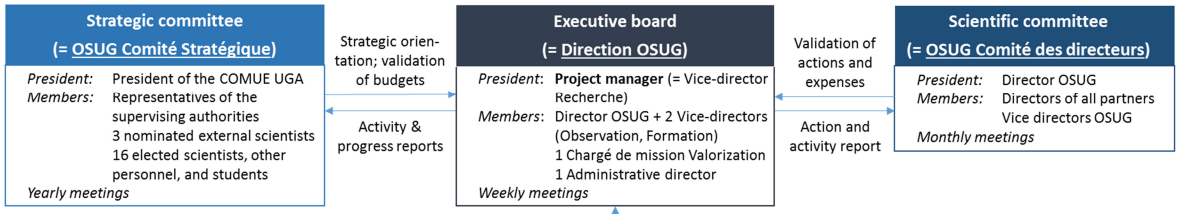
5 PARTNERSHIP

5.1 GOVERNANCE

The decision-making structure for the prolongation period is with two modifications the same as the present governance model and is mostly based on existing OSUG entities to increase efficiency and acceptance (Fig. 3). The **Executive Board (EB)**, corresponding to the OSUG Directorate, is responsible for overseeing the day-to-day operations. The EB is chaired by the **Project manager (= OSUG Vice-director Research)**. The **Scientific Committee (SC)** is the highest project authority supervising the implementation. It includes all laboratory/team leaders and the EB. It is chaired by the OSUG director and establishes strategic directions and maintains the overview of the project towards the successful completion. It validates actions, projects, and expenses proposed by the EB. The SC will meet monthly and decisions will be made by majority vote if necessary. The EB can call extraordinary SC meetings and promotes actions towards the SC concerning unexpected issues. The project is advised by a multi-disciplinary **Strategic Committee (StC)** corresponding to the OSUG *Comité stratégique* with representatives of each involved academic institution and organization, three nominated external scientists (P. Braconnot, LSCE Paris; C. Reylé, Obs. Besançon; E. Calais, ENS Paris), and 16 elected members representing the different categories of OSUG staff. Annually, the StC analyses critical issues concerning the objectives, the integration into local and national efforts, and advises about the project strategy. The first modification concerns the **Chargé de mission Valorization** (see 2.3) as an additional member of the EB. With this new function we intend to regroup our communication, outreach, and trans-disciplinary activities and to propel them to the next level. Second, currently separated Commissions Research and Observation will be regrouped into a combined **LabEx Commission Research/Observation** for the selection of research projects. This commission is chaired by the project manager and consists of the OSUG Vice-director Observation, eight representatives for the scientific axes, two for the analytical platforms, two for the IARS, one for OSUG-DC, and one for each RI (Table 1).

Like in the initial phase **regular project calls** open to the entire community will be launched for PhD theses and research, higher education, outreach, and communication actions. Distribution of resources will be based on the scientific quality of the projects, their innovative approaches, and their relevance within the work program. Long-term actions concerning **strategic funding** like investments for the scientific program (see 4.2), high-level schools, and outreach and communication actions will be financed with recurrent funding and will be **selected in the initial phase**. Further

actions will be selected upon annual project calls. Projects will be evaluated and selected by the Commission Research/Observation or existing OSUG commissions (Formation and Communication), while all selected projects will be validated by the SC.



	Commission Recherche/Observation		OSUG Commission Formation					OSUG Commission Communication	
	Research & observation projects	PhD grants	PhD trainings	BSc & MSc programs	MSc scholarships	High-level schools	Intertropical trainings	Outreach	Communi-cation
Annual calls	X	X	X	X	X		X		
Recurrent funding	X					X		X	X

Figure 3: Governance scheme for the project. Existing OSUG entities are underlined.

Due to the project we intend to increase the fraction of publication with **authors from different units** to 15% of all OSUG publication. After five years, the scientific results will be presented at an **open international symposium** linked to the project topics resulting in **four reviews** for the scientific axes involving authors from multiple partners. **10 (co-)funded PhD theses** will be realized, from these at least two will be in cooperation with the LabEx ITEM and two will be carried out with international thesis co-advisers. We will organize **five issues of the high-level school *Habitability in changing worlds*** open to international students, contribute to the implementation of **two inter-university co-diplomas**, and will support actions reaching out to more than **hundred students from inter-tropical countries**. We intend at least **ten large outreach actions** for different audiences.

5.2 CONSORTIUM MODIFICATIONS

A slight modification of the consortium is proposed with the **inclusion of SAJF (Alpine Field Station of Lautaret)**, member of OSUG since 2014. SAJF provides off-campus facilities for research and education focusing on mountain environments at 2100 m altitude and will be a vital element for the MRS. It is a member of the AnaEE network and is a major host for the Transnational Access Program of E-LTER. Its observational and experimental infrastructure has already been used by several OSUG@2020 projects related to **observing and modeling of the dynamics of mountain socio-ecological systems** and **understanding of the climate and biogeochemistry of mountain ecosystems** in line with the project priorities. SAJF fosters **tight interactions between Geosciences, Ecology, and Social Sciences** on topics like snow-vegetation processes, nutrient cycling, ecosystem fluxes, and the evaluation of services provided by mountain ecosystems. SAJF is regularly hosting high-level schools and training courses for graduate students. SAJF has **~15000 visitors each summer** providing unique opportunities for dissemination actions towards a diverse international public.

5.3 PARTNERS' DESCRIPTION, RELEVANCE AND COMPLEMENTARITY

OSUG is in charge of personnel and common services dedicated to monitoring activities: SNO, OSUG-DC including high-performance computing and distributed IT services, dissemination,

communication, and administration. OSUG associates the involved units and research teams in a so-called *Fédération*. **IGE** conducts research on climate, the water cycle, cryosphere, natural environments, and environments under anthropogenic impact to understand processes that govern the ocean, the atmosphere, the cryosphere, watersheds, and the critical zone, their interactions and responses to human pressures. **IPAG** covers all aspects of Astrophysics and Planetary Sciences and is geared towards investigating the conditions for star and planet formation, high-energy phenomena, and habitability beyond Earth. The major objective of **ISTerre** is the physical and chemical study of the Earth system by combining observations, experimentation, and modeling focusing on earthquakes, landslides, Earth and core dynamics, fault mechanics, volcanoes, mountain belts, georesources, and natural and anthropogenic pollution. The **Irstea** Grenoble Centre conducts research and develops expertise related to natural hazard prevention, mountain ecosystems and territories, and the dynamics of socio-ecosystems in mountain regions. **LECA** aims at understanding ecosystem functioning and the maintenance of biodiversity by describing biodiversity patterns, understanding evolutionary and ecological processes, and modeling the mechanisms related to environmental dynamics and forcing. Research activities conducted at **LEGI** combine modeling, testing, simulation, and the development of instruments for applications in mountain meteorology and pollution, sediment transport on beaches and in rivers, and the dynamics of oceans and the atmosphere. **CEN** focuses on snow science, develops expertise for avalanche forecasting and contributes to the development of meteorological and climate services in mountainous areas. **SIGMA-Phy** develops information processing methods (including machine and deep learning) for the analysis of signals and images for environmental observation. **Environnements** studies socio-environmental dynamics and key concepts related to adaptation, biodiversity, energy, risks, and landscape. **FAME** focuses on Geochemical Sciences using high-energy resolution x-ray absorption for structural investigation of environmental samples. **LAME** applies absorption spectroscopy to the characterization of atmospheric and extra-terrestrial molecules and the quantification of trace compounds and their isotopes. For **SAJF** see 3.2.

The participating units and teams regroup more than **380 scientists** and **220 technical and administrative staff** bringing all required scientific and technical expertise to implement the highly interdisciplinary project. While each of the units brings its **excellent and recognized expertise** in several large domains, the teams, which are also part of larger units outside our domains, bring their expertise in crucial niches. For example, SIGMA-Phy develops new methodologies and tools in signal and image analysis in collaboration with thematic experts from other units, which provide their expertise in the considered applications, physical modeling, etc. **Strong ties and tight collaboration** have been developed in the initial phase of the LabEx with respect to all supported activities from research to valorization and dissemination. These links are now exploited on a daily basis and helped securing the strong involvement of the project members in the RIs. They are also the basis for a range of newly initiated interdisciplinary projects like the CDPs and others.

6 FUNDING JUSTIFICATION

6.1 EXPENSES JUSTIFICATION

The implementation of the project requires funding for scientific equipment, personnel, and running costs. **Investment in equipment totals ~1.3 M€**, while **~1.6 M€** will be spent **for estimated 745**

person-months (p-m) of Master and PhD students and scientific and technical personnel like Postdocs, engineers, and technical staff supporting actions related to research, observation, scientific computing, education, communication, and valorization activities. The budgets for research, education, and valorization activities are in the order of 3.3 M€, 1.1 M€, and 0.5 M€, respectively. The remaining 0.4 M€ account for overhead costs.

Concerning research activities, **1 M€ of the budget will be invested in the first two project years in strategic activities** concerning all four scientific axes. We expect that these strategic investments will concern salaries for postdocs or technical personnel (total 250 k€) or novel analytical or field equipment with budgets ranging from 30 to 300 k€ (total 750 k€). For example, during the initial period the acquisition of a thermos gravimeter (~40 k€) and a liquid chromatograph coupled to a mass spectrometer (~300 k€) were financed. For **each scientific axe**, additional **0.55 M€** are reserved. Within the research budget we will finance **five full PhD scholarships** (0.5 M€), which we intend to raise to ten with co-funding. Similar to the initial phase of OSUG@2020 we expect an overall distribution of approximately 35 % investment, 20 % salaries, and 35 % running costs (e.g. field trips, analytical costs, or small equipment) for the research budget. At this stage these **costs cannot be specified further** since the participating units and teams **continue raising significant co-funding** until the start of as well as during the prolongation period and exact investments and expenses will be decided upon project calls open to all units and teams (see 3.1).

The **education budget** includes mainly **equipment** related to the *Campus de l'Environnement* and supports for **innovative actions in BSc & MSc programs** (20%), **technical personnel** for formation actions (10%), and running costs for **international exchanges** of students and researchers (70%) including 0.25 M€ dedicated to exchanges with inter-tropical countries. The budget for **valorization** covers mainly the salaries for additional **personnel** (75%) and **running costs** for communication, outreach and transdisciplinary actions (25%) like the final symposium or further workshops.

6.2 FUNDING PLAN

The ambitious project can only be realized due to **significant contributions of the project partners** concerning human resources and equipment. **Approximately 10% of the permanent staff** in all units and teams will be **involved in the project throughout the prolongation period** matching **more than 2200 and 1300 p-m of scientific and technical/administrative personnel**, respectively, equal to an **overall budget of more than 29 M€**. The permanent staff will contribute to scientific, teaching, and valorization actions including the supervision of the financed students, Postdocs, and other personnel. Moreover, the project will be realized with available important facilities and equipment. Besides instrumentation acquired during the initial period (here not accounted for), this concerns **large-scale analytical and experimental facilities** like FAME or the CORIOLIS platform at LEGI, **cold- and clean-room facilities** at IGE, CEN, and IPAG, **experimentation halls** for astrophysics or civil engineering at IPAG and Irstea, and **state-of-the-art instruments** like an electron probe micro analyzer, a geophysical tomograph, electromagnetic tools and probes for hydro-geophysics, an ion trap mass analyzer, spectrometers or further analytical equipment at ISTerre, IGE, and IPAG. We estimated that at least **14 M€ has been invested in the recent years** in this equipment, which will be made accessible to all participating units and teams.