Annex: List of questions to be addressed by HPC CoE projects

(1) *User-driven, with the application users and owners playing a decisive role in governance:*
Who are the users, which application, what is the role of the users?

The weather and climate community work together on a range of projects which span "near term science and infrastructure" through to "over the horizon technical" activities. In doing so they exploit existing HPC technologies and they contribute to the scoping of future HPC technologies and facilities. In contrast to existing EC projects (such as the IS-ENES series of projects) which concentrate on current and near term science and infrastructure, ESiWACE has been set up to prepare HPC applications in weather and climate for the future with grand challenge and next generations problems in mind.

The direct users of ESiWACE span the model developers and HPC architects who are preparing for future heterogeneous multi-core HPC developments. The work of these direct users will allow partner institutions to exploit these next generation tools to deliver scientific results relevant to the policy and security of their nations and the global community. Future users could also include any private sector companies that arise to exploit climate and weather services. Other indirect users include the supranational bodies such as the World Meteorological Organisation's (WMO), the World Climate Research Programme (WCRP), and the World Weather Research Programme (WWRP). At this highest level, the economic and societal benefits of more accurate weather forecasts and climate projections are wide ranging, affecting both our safety and efficiency making the whole of society a beneficiary of the work.

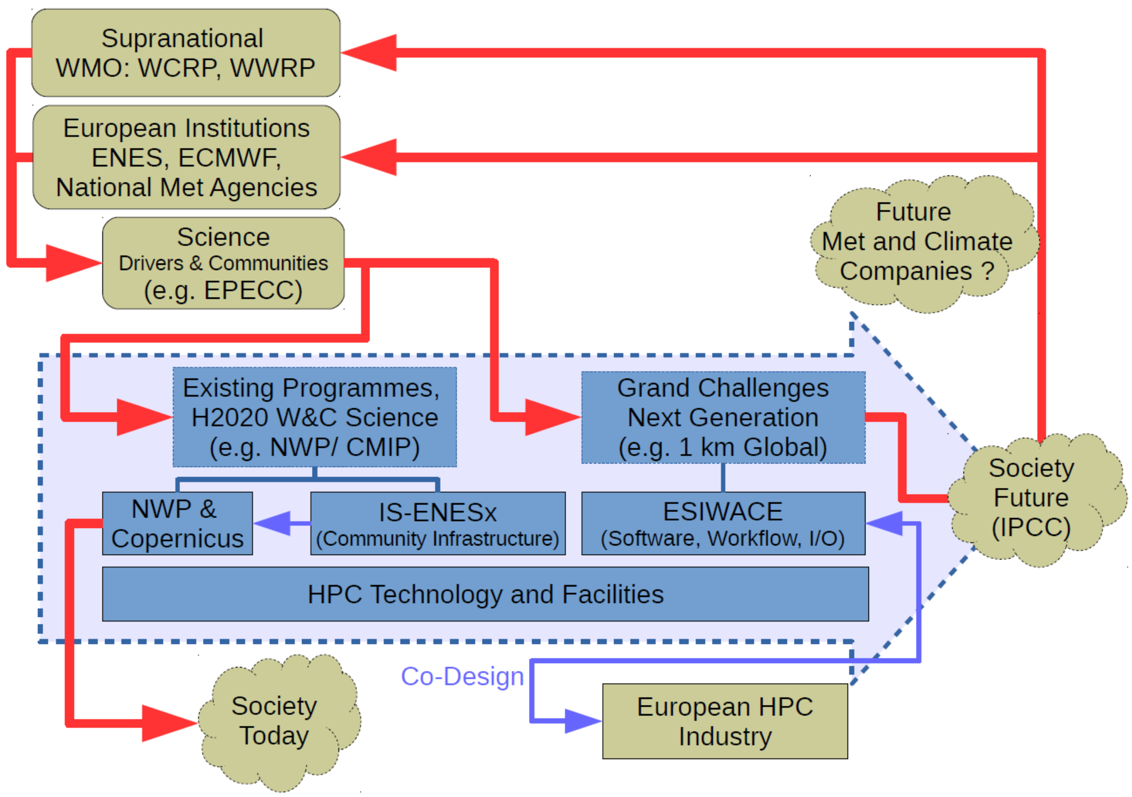

Figure 1: Direct, indirect and potential future users of ESiWACE.

The primary grand challenge chosen by ESiWACE is to be able to efficiently run global convective cloud-resolving models with a 1km resolution in a 50-member ensemble configuration on future generation HPC systems. The problems anticipated during this challenge will be not only computational, but will also involve workflow, I/O and data issues, and the solutions developed within ESIWACE will be applicable to a wide range of Earth simulation problems for weather and climate on a wide range of spatial and temporal scales.

By interacting directly with domain specific experts who are strategic thinkers, ESiWACE will gain a better understanding and have a greater influence over the plans for exascale within the community. The Governance work-package will oversee and facilitate this communication working with the work-package leads.

Our defined direct users have been and continue to be intimately involved in the specification of ESiWACE, from the design of the programme through the very specification of the grand challenge (the 1km global goal has been made explicit in European objectives since the 2012 ENES foresight strategy, recently underlined in the EPECC proposal for future and emerging technology funding). The advice received from the ESiWACE scientific advisory board is another example of communication with the direct users. Users are also intimately involved in the delivery of ESiWACE – the users making the key technology strategy decisions for their institutes will be the same people making decisions for ESiWACE either from within the project or via the domain specific communication channels we propose. What is new here will be the joint approach to establishing technical directions and decision making in ESiWACE – both informed by and influencing "above" and "below": "above" through (i) the supranational programmes via strategic scientists within our institutions and (ii) the advisory board; "below" through colleagues from ESIWACE partners and supporting organisations or within other projects (including other HPC Centres of Excellence).

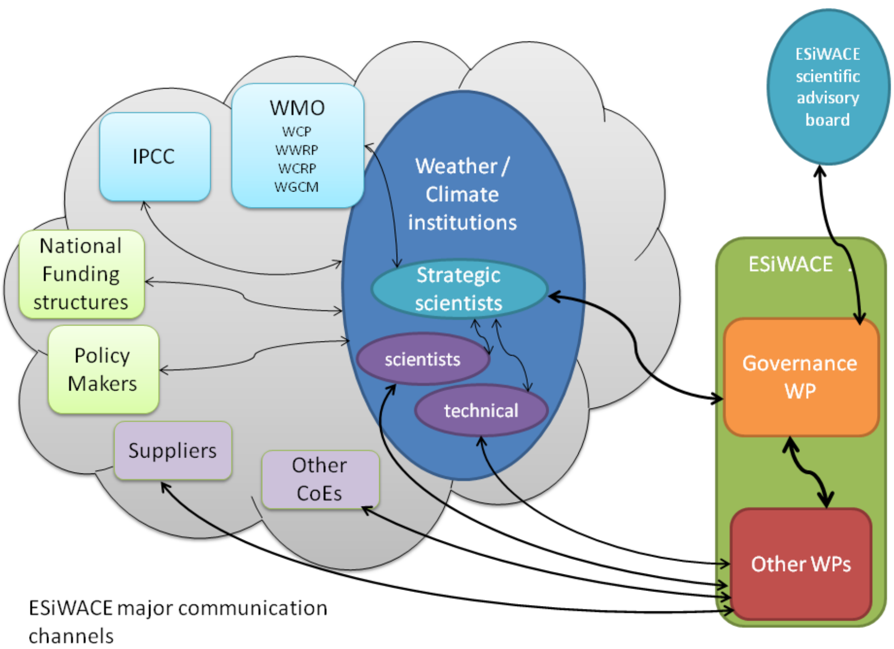

Figure 2: ESiWACE communication channels

By working through the weather and climate institutions to communicate with the national funding structures and supranational organisations (IPCC, WMO etc.), we ensure that our approach is relevant to the direct end users at the organisational level. These indirect users (national and supranational) are interested in the scientific output and not the technical means of delivering it and the weather and climate institutions have well established interactions with these bodies.

(2) *integrated: encompassing not only HPC software but also relevant aspects of hardware, data management/storage, connectivity, security, etc.; :*
What type of integration and how it will be implemented?

For ESiWACE, integration means a programme of activity that considers as many of the relevant aspects of solving the problem of the ESiWACE science challenge as is practical within the project and to act as a hub for sharing the expertise and best practice that exist within the community. This integration started with the development of the proposal, which analysed the range of technical challenges faced by the weather and climate modelling communities. The challenges selected were both common and important and covered items in all major areas:

- Scalability. As we increase model resolution and complexity, we need models to radically improve their scalability.
- Usability. In order to exploit massively increased computing resources without a significant increase in the number of people involved in the science and operation of those models, we need to see a step change in the ease of use of our modelling systems.
- Exploitability. Disk and tape technologies are not evolving at the same rate as compute technologies and so a step change is required to support the data part of our workflow as we move to exascale.

The management work package, using the ESiWACE science challenge as a focus, will be responsible for ensuring an integrated approach around this common challenge within the project. The governance work package will support this by bringing in information from the following key groups:

- The weather and climate communities at the strategic and working levels both with project partners and with supporting organisations;
- HPC related programmes within Europe;
- The HPC industry.

(3) *multidisciplinary: with domain expertise co-located alongside HPC system, software and algorithm expertise;*
Which expertises are available?

ESiWACE puts together a blend of expertise covering HPC industry and operational HPC services as well as the leading edge weather and climate modelling. By integrating the broad community of users, the project will be able to get access to many relevant areas of expertise. Focusing on the grand challenge, partners will focus on development and scaling of climate and weather models towards the extreme scale, on evaluation and optimisation of specific model components and on data management on different architectures through, among others, development of methods for exploiting storage supports. The usability of all resources will be enhanced with tasks dedicated to benchmarking, co-design and development of best practices.

Specifically, the project has access to the following skills within the work-packages:

- Climate and weather modelling (in particular NEMO, ICON and EC-Earth) including the skills required to balance performance, scalability and scientific fidelity or approaches and algorithms;

- Model coupling and IO (in particular OASIS and XIOS);
- Performance analysis, optimisation, scalability, benchmarking and energy efficiency;
- HPC platforms (hardware and software) through industry partners;
- Weather and climate data expertise able to seek new workflows that are more efficient;
- Expertise in workflow solutions that can be used for both climate and weather in research, development and production environments;
- Software environment expertise;
- Expertise in permanent storage hierarchies and the relevant weather and climate data formats.

(4) *distributed with a possible central hub, federating capabilities around Europe, exploiting available competences, and ensuring synergies with national / local programmes;*

What steps are being proposed? Anything missing and its significance?

The expertise in weather and climate modelling is distributed among different centres in Europe with a set of different models. Indeed, diversity in climate and weather models is required since there is no unique way to represent the complexity of the Earth system. ESiWACE aims at strengthening HPC applications in the field and preparing for future architectures by enhancing collaboration among climate modelling centres, between climate and weather modelling and between the climate/weather communities and ICT industry.

For this integration, ESiWACE relies on two well established European networks, namely (1) the European Network for Earth System modelling (ENES), representing the European climate modelling community contributing to the internationally coordinated experiments of the World Climate Research Program (WCRP) and the Intergovernmental Panel on Climate Change (IPCC) assessments, and (2) the world leading European Centre for Medium-Range Weather Forecasts (ECMWF), an independent European organisation supported by 34 member and cooperating states, and also the operator of the Copernicus services for atmospheric monitoring (CAMS) and climate change (CCCS). ESiWACE also benefits from European collaborations on the European ocean modelling platform NEMO and on the coupled climate model EC-Earth based on the ECMWF weather model, as well as from some sharing of community tools developed through ENES and its IS-ENES projects.

ESiWACE also benefits from national and institutional on-going efforts on HPC applications such as the development of a new generation of climate models (DE, UK, FR), the ECMWF Scalability programme. ESiWACE brings together partners, among which institutions with international standing, from seven European countries and is an opportunity to share on-going developments at national and institutional levels.

Building on this existing expertise, ESiWACE aims at tackling key gaps related to HPC applications in the field of climate and weather i.e. to address the challenge of preparing for future architectures and to reduce the technical burden associated with HPC applications by enhancing sharing on software. These challenges were emphasised in the ENES infrastructure strategy 2012-2021 and were recently underlined by 20 leading European scientists in a proposal to establish a European Programme on Extreme Computing and Climate, EPECC.

In order to address these challenges, ESiWACE takes the following steps:

- Prepare for future architectures: test some high-end science cases to understand main challenges; investigate different ways to enhance scalability; investigate new file systems better suited for data-intensive climate and weather applications.

- Accelerate the use of high-performance computing: share expertise on all workflow components, optimise IO servers such as XIOS, optimise the common European coupler, optimise common European codes such as NEMO and IFS (part of ECMWF and EC-Earth models), and the use of high-level tools for workflow

Developing the next generation of climate and weather codes and related environments for exascale is a long-standing issue, beyond what ESiWACE can do in 4 years, but to which ESiWACE will pave the way.

ESiWACE is also a unique opportunity for scientists to work with industry. It investigates possible co-design for present and future developments and establishes fruitful links to the other HPC European actors through EXDCI.

The project benefits synergies with existing national and institutional programmes, and several joint European efforts in place:

- ECMWF:
    - ECMWF is running a so-called Scalability Programme that aims at enhancing the efficiency of those computing and data handling tasks that drive HPC cost and that inhibit flexibility of scientific choices. The individual projects focus on observational data pre-processing, data assimilation, forecast modelling, model data post-processing, programming models and code design, and computing architecture support. ECMWF's tasks in ESiWACE are in line and thus integrate well with various tasks in the Scalability Programme, namely programming models, data compression, and model component parallelisation (concurrency), but also with ESiWACE community support actions like the provision of OpenIFS for ESiWACE disseminating computing science developments.
    - ECMWF coordinates the ESCAPE project which targets selected forecast model components, the underlying algorithms, their numerical implementation and code adaptation to novel computing architectures. ECMWF also contributes to NextGenIO for data handling optimisation exploiting NVRAM technologies, and to EPiGRAM for testing programming models enhancing parallel data communication.
    - ECMWF regularly runs benchmarks for anticipated future configurations of the forecast model, mostly with respect to spatial resolution and model complexity. These benchmarks also aim at testing ECMWF model performance on different hardware technologies. ESiWACE will directly benefit from these benchmarks as these runs will support the assessment of the computability of future high-resolution models, and the definition of requirements for processor speed, bandwidth, memory allocation, network design, and other aspects of HPC system design.
    - Developments performed by other ESiWACE partners will reciprocally support the above ECMWF efforts.
- DKRZ/MPG:
    - DKRZ and MPG have a longstanding joint expertise in climate simulation, ranging from the simulation of local area models to global earth system models. In this scope, they are a role model for a national central hub for climate modelling.
    - DKRZ provides various services to the weather and climate community, for example the data management services WDCC/CERA.
    - MIKLIP is a national project of 15 partners including DWD and MPG, developing the research version of the comprehensive earth system model mpiesm-1 for decadal climate prediction into an operational version.
    - One aim of the model development of ICON is to provide a scalable model to tackle "grand challenge" questions. ICON is capable of simulating all scales from Large Eddy Simulations (national project HD(CP)2 with leading

involvement by MPG, DKRZ and DWD together with 17 other national institutions), detailed high resolution studies (NARVAL campaign) to weather forecast (DWD) and climate projections. The framework in use and development consists of several components such as atmosphere, ocean and chemistry (in the atmosphere and ocean) sub-models, high-performance communication (YAXT) and low level output (cdi-pio) libraries as well as a specialised coupler for unstructured grids (YAC).
    - DKRZ, MPG and DWD are partners in the national funded lighthouse project HD(CP)2 (High Definition Clouds and Precipitation for Climate Prediction). The target of the project is to run the ICON model for Large-Eddy simulation (ICON-LES) with very high-resolution (horizontal spacing of 100 m). The strategy to optimise the set up and running the model here will be of great importance for the ESiWACE work packages.
    - MPG develops workflow components such as the parallelised post-processing tool cdo (Climate Data Operators) with the underlying flexible I/O library cdi. This one is capable of handling the two dominant data standards in the community - grib and CF/netCDF. Work has been invested to provide additional compression schemes to grib2 (libaec). Future developments are targeted to improve the density at all levels of tasks on HPC platforms (fine-grained DAG based functional evaluation of tasks) including model components, post-processing workflows including streaming (with ECMWF), and meta-scheduling (cylc, NIWA, UKMO).
    - The exploration and adaptation to new architectures is work in progress by studying different types of coding standards and DSLs (collaboration of MPG, DKRZ, ETHZ and CSCS) with GPUs as a first target.
    - Employing national funding from PalMod, MPG, DKRZ and colleagues work on the scalability of low resolution models for simulation of very long time periods (ice ages).
- CNRS-IPSL:
    - CNRS-IPSL is strongly involved in the developments of NEMO ocean platform, in particular with regards to HPC performance. It leads the NEMO system team and chairs the NEMO Consortium steering committee.
    - CNRS-IPSL, with its third party CEA, develops the XIOS IO server which is included in all components of the two French climate models. This is supported by the national project Convergence. XIOS is also used in the EoCoE center of excellence.
    - CNRS-IPSL is preparing its next generation climate model for massively parallel computing, based on the new dynamical core DYNAMICO.
    - CNRS-IPSL is engaged with the European climate modelling community as chair of ENES Board, coordinator if its infrastructure and through its task forces on HPC and data.
- CERFACS:
    - At CERFACS, the internal "DECLIPP Challenge" aims to develop new methods to address the problem of decadal prediction based on the development and use of a coupled ocean-atmosphere model that is well aligned with the ESiWACE grand challenge,
    - CERFACS is leading the development of the OASIS coupler for more than 25 years, now in collaboration with CNRS, which is used by more than 45 climate modelling groups around the world, among which at least 25 in Europe.
- BSC:
    - The BSC mission is performing research on and developing methods for environmental forecasting, with a particular focus on the atmosphere-ocean-biosphere system. This includes managing and transferring technology to support the main societal challenges through the use of models and data applications in HPC and Big data infrastructures.

    - The BSC aims at developing a climate prediction capability for time scales ranging from a few weeks to a few decades (sub-seasonal to decadal climate prediction) and from regional to global scales. This objective relies on expanding our understanding of the climate processes through a deep analysis of the strengths and weaknesses of state-of-the-art climate forecast systems.
    - BSC provides help and guidance on the technical aspects of the scientists' work and has to develop a framework that ensures an efficient use of high-performance computing resources. In order to keep an efficient use of the variety of computing resources available at the BSC and at other HPC institutions, a solid software development, profiling and optimisation area has been created to provide feedback to Earth system modellers around Europe on how to improve their codes in the race towards exascale computing.
- METO:
    - The Met Office programme invests in the development of the Cylc meta-scheduler for the benefit of a wide range of Met Office partners and collaborators including but not limited to both weather and climate workflows.
    - In the LFRic and GungHo projects, weather and climate models that are suitable for exascale computing are developed. The performance and scalability of OASIS and XIOS are of particular relevance to these projects.
    - The Met Office weather and climate programmes both rely on NEMO and intend to do so through to exascale.
    - The Met Office has a programme of development of the moose system to get high performance from tiered storage including tape archives for climate and weather data.
    - The GW4 alliance (Universities of Bath, Bristol, Cardiff and Exeter) have partnered with the Met Office to procure an EPSRC Tier-2 system from Cray. This will provide a capability to consider code performance for a variety of different processor families with a consistent compiler/software stack which will help us understand the challenges and opportunities of future architectures.
- STFC and UREAD:
    - STFC and UREAD are together (within the UK National Centre for Atmospheric Science) exploiting the same modelling infrastructure as the Met Office, so expect to benefit from ESiWACE in the same areas as listed above under Met Office.
    - They are both responsible for delivering national and international data archives and next generation data intensive computing environments. The work on Cylc, storage modelling, layouts and tiers will be of especial benefit, and to that end, NCAS expects to find extra co-funding to contribute to this work, especially on the storage elements.
    - NCAS at the UREAD is also responsible for supporting weather and climate model usage in the wider UK academic community where work on workflows will be of especial benefit.
- SMHI:
    - SMHI is co-leading (together with CERFACS) WP JRA1 of IS-ENES2, which has the task of designing and implementing multi-model multi-member high-resolution ensembles of European ESMs. Thus, SMHI participates in a coordinated model development project that is dedicated to high-resolution ESMs and computational performance.
    - SMHI has a leading role in the development of EC-Earth. The institute coordinates development activities and maintains the source code of the model. SMHI publishes releases and provides the EC-Earth Development Portal, which is the main collaboration platform for the EC-Earth consortium.

    - SMHI has initiated a collaboration with the ECMWF about an integration of OpenIFS and EC-Earth in 2013. Since then, SMHI has been dedicating resources for the development of EC-Earth/OpenIFS, which has led to the release of a proof-of-concept model version, to be used as the starting point in ESiWACE.
- ICHEC:
    - ICHEC operates NWP on behalf of Met Éireann, and collaborates on weather and climate model operations and scaling. Working within the EC-Earth climate model community and weather model development (Hirlam, ESCAPE projects), and publishing climate and NWP data via the Earth System Grid. Benchmarking and tool development (especially for IO and postprocessing) are important for ICHEC, and the results of ESiWACE will directly benefit this work.
- CMCC:
    - The CMCC Strategic Projects programme invests in the performance analysis and computational improvement of the NEMO model to get high performance from emerging architectures. The programme is focused on proposing new coding approaches to increase the exploitation of the HPC systems' peak performance and to limit the parallelisation overhead; the performance and scalability activities performed in ESIWACE and the ones faced by this programme are of mutual relevance.
    - The CMCC Strategic Projects programme invests in the Ophidia framework for high-performance data analysis and parallel diagnostics, including but not limited to both weather and climate data. The activities on storage modelling, layouts, and workflows performed in ESIWACE and the ones on scientific data management addressed by this programme are of mutual relevance.
- DWD:
    - DWD, the German national weather service, has been developing and employing HPC applications in numerical weather prediction for many decades. The DWD represents German interests in international meteorological and climatological organisations, operates its own HPC compute and data center, and is collaborating with a wide range of institutions in this area, cf. amongst others section DKRZ/MPG above.
    - In particular, DWD's currently operational global model ICON is the product of a close collaboration with MPG and DKRZ. The ICON model is based on icosahedral grids and thus meets a major prerequisite for high scalability.
    - The BMBF funded project HD(CP)2 further stimulates the development of the ICON model towards exascale. Both, MPG and DKRZ are also involved in this effort to identify and resolve future scalability bottlenecks, cf. section DKRZ/MPG above.
    - Further intense collaboration and mutual exchange of experience is provided through DWD's central role in the COSMO consortium for small-scale modelling.
- SEAGATE:
    - SEAGATE is among the world-leading providers of data storage devices, equipment and services, also addressing extreme performance HPC.
    - SEAGATE has previously been and is still involved in storage solutions at DKRZ as well as in the EU projects DEEP-ER and SAGE.
    - SEAGATE sees a real opportunity through the ESIWACE consortium partnerships to gain in depth co-design inputs to enable future data storage systems to become deeply aware and optimised for the predominant data storage and management techniques used within the communities represented by the Centre of Excellence. This is a true win-win opportunity where new and evolving storage methods suited to extreme scale environments will be prepared in cooperation with the community they will required to serve.

- BULL/ATOS:
    - In collaboration with DKRZ, which has a Bull Peta-Flop machine used to run climate applications, Bull is involved in the optimisation of ICON, especially in improving the library developed by DKRZ used for communication of the domain halos between processes.
    - As part of the ESCAPE project, Bull co-leads the work package on hybrid computing which aims at optimising the exploitation of alternative technologies and specialised accelerators in a hybrid environment. Bull especially works on performance models including energy models, on the optimisation of computational kernels called "dwarfs" for Xeon Phi and on its porting to multi-node systems.
    - In collaboration with LNCC (National Laboratory of Scientific Computing), which has a Bull supercomputer system (Santos Dumont), Bull has worked on the porting and the performance analysis of the application BRAMS (Brazilian developments on the Regional Atmospheric Modelling System) to Santos Dumont.
    - In collaboration with AEMet (State Meteorological Agency, Spain), Bull has worked on several applications' optimisations: MOCAGE, Harmonie and WRF.
    - Bull has worked on porting MESONH and DYNAMICO to Xeon and Xeon Phi, including node to node performance comparison (KNL vs BDW, KNL vs HSW) and high level tuning parameters for KNL.
    - In collaboration with Intel, the goal was to port NEMO to manycore architectures. Bull optimised a small dozen of kernels to make them take benefit from manycore systems. At the end, optimisations on Phi were also useful on the latest x86 architectures (vectorisation).
    - Bull has performed the porting of AROME to an ARM based system.
- ALLINEA:
    - ALLINEA Software provides tools to assist application scientists in the development and debugging of scientific codes. ALLINEA tools are designed to assist in the optimisation of HPC applications, for increased efficiency, a key consideration within the ESiWACE project.
    - ALLINEA has existing working relationships with a number of ESiWACE partners, including ECMWF, METO and DKRZ, to support climate and weather research. ALLINEA brings a wealth of experience with HPC environments and emerging technology, and is strategically placed to educate the user community on industry best practices.
    - ALLINEA has existing collaborations with a number of different user communities within the HPC industry, through existing European projects. These additional co-design activities will help consolidate the requirements of different user communities to help influence both hardware and software vendors, to further the industry as a whole.

ESiWACE will also maintain connections with

- European FET projects such as ESCAPE and co-design projects to be funded under FETHPC-1-2016
- Other CoEs, in particular POP, EoCoE and CoeGSS
- Related domain specific projects and activities, such as IS-ENES2 and the EPECC initiative

Participation in cPPP and other ETP4HPC and EXDCI organised events will ensure that relevant projects and initiatives are being identified and contacted. In particular, several project partners (co-coordinator ECMWF, ATOS/BULL, Seagate, Allinea, BSC) are formal members of the ETP4HPC and are contributing to the SRA. In particular, we are through coordinator and co-coordinator directly involved in the working group discussing the proposal for extreme scale demonstrators (EsDs) where we emphasize that adequate representation of applications must be considered key for a successful deployment of such EsDs and that accordingly sufficient resources are mandatory to ensure porting and adaptation of applications to next generation supercomputers.

(5) *Provision of services such as: developing, optimising (including if needed re-design) and scaling HPC application codes towards peta and exascale computing; testing, validating and maintaining codes and managing the associated data; quality assurance; co-design of hardware, software and codes; consultancy to industry and SMEs; research in HPC applications; and addressing the skills gap in computational science.*
How close to exascale? Which and what co-design will be implemented and when results are expected? Which codes will be available? Which will be Open source? What co-operation with SME is expected?

Scientifically, weather and climate models are very close to being suitable running at 1km - the ESiWACE Science challenge. This can be shown when models are run over smaller regions or for short periods. However, the models themselves do not have the scalability and parallelism to run quickly enough for the global science challenge. Major weather and climate centres have programmes to move to new dynamical cores, which are one of the key algorithm changes that will be required to exploit exascale computing. By focusing on the ESiWACE science challenge, providing metrics and a timetable, ESiWACE will support these local programmes (see question 4).

For many years the word "co-design" has been used but the reality is that hardware development has driven ahead and software has not been able to keep up. The economics of HPC development is such that HPC systems are increasingly reliant on commodity hardware with drivers that are very different to the typical HPC applications. The timescales for software development, partly linked to the resources available, imply that in our community the software is increasingly lagging behind the hardware trends. The situation is becoming even worse as effective hardware alternatives emerge and architectures become more and more complex: Accelerators (Intel Xeon Phi, GPGPU), ARM, memory hierarchy, burst buffer, network topology. HPC suppliers are required to integrate components from an ever increasing number of manufacturers with relatively independent development programmes.

The situation is complex and far from ideal. In this context and within the constraints of funding, the aim of ESiWACE is to demonstrate the benefits of (i) in-depth engagement with suppliers on specific topics and (ii) the increased influence of a community wide engagement of common issues. Three areas have been targeted: (i) high-performance IO of meteorological data where an in-depth engagement has been proposed with Seagate; (ii) full system integration with Bull where the aim is to get a better understanding of common issues in the community through the analysis of the potential influence that an integrator can have on the full supply chain and (iii) ALINEA to understand the ability of HPC software suppliers to help solve the challenges on increasingly complex HPC systems.

Further, by developing a road-map that represents the needs of the whole community, we will be able to use this as a vehicle for influencing HPC and sub-suppliers including those outside ESiWACE.

ESiWACE builds on established services around existing widely shared open source model components, such as the OASIS coupler, the NEMO ocean model and the CDO processing tools. A central work package deals with governance of such common tools and with assessment, evaluation and prioritisation of tools and services required by the users. This will be done in cooperation with the users and the industrial partners (but also external private bodies) and shall lead to a sustainable business and service model. For example, Allinea plans to work with project partners to understand the debugging and profiling requirements of the user community, and to educate on best practices. ESiWACE co-design will facilitate a better understanding of ESM workflows and allow future developments of Allinea tools to better cater for the ESM communities. Existing collaborations with the Met Office have enabled the

support of Allinea tools within the Cylc metascheduler. Further co-design will increase this level of integration and optimise for the ESiWACE use cases.
ESiWACE also moves into new areas through the usability and exploitability work-packages, providing services in workflow solutions and acting as focal point for development on new methodologies in software environments and data handling.

(6) *Working in synergy with the pan-European HPC infrastructure, including by identifying suitable applications for co-design activities relevant to the development of HPC technologies towards exascale. Sustainability embracing a wide range of service models and funding from a mixture of sources, including through sponsorship by industry or hybrid public-private models. Clear business plans are expected to be presented in the proposal.*
Which service models are proposed and how that will be implemented?

ESiWACE proposes services to the weather and climate community at different levels:

1. Development and sharing of some common software able to accelerate progress in development and applications in the field;
2. Sharing of expertise and synergies of efforts to prepare for future architectures, actually reducing the time to solution.

The wider user community of ESiWACE includes the academic and operational services working in climate and weather. Beyond the consortium members, ESiWACE interacts with this community through the networks from ENES and ECMWF. Supporting members have already expressed their interest in ESiWACE and are a key target community to interact with. They benefit from levels 1 and 2 services. Level 1 includes well-established software used by a large community, such as the coupler OASIS and the European codes NEMO and IFS, as well as more emerging software such as the IO server XIOS and the meta-scheduler CYLC. Level 2 is more diverse. It includes reporting on optimisation of representative codes such as NEMO, IFS and ICON, as well as from science cases. It also includes new developments such as on the data file system that could become relevant for new services, as well as the exploration of possible co-design.

Most of the efforts and financial support initiatives in weather and climate modelling are carried out at national level. Some first experiences, as the NEMO and EC-Earth consortia, show that common software development at European level is indeed feasible and worthwhile on an institutional basis. European funding, however, plays a key role in allowing the number of common tools and the degree of sharing to gradually increase.

One of the tasks of ESiWACE is to prepare a plan for a sustainable service and community work (month 38). We are investigating the following non-mutually-exclusive solutions to guarantee long-term project legacy:

- To reach an agreement between partners on common software, which preliminarily requires reaching a critical mass of shared items.
- To identify needs for future standards in Earth system modelling software facilitating model development and applications.
- To plan common work on developing next generation of models able to address exascale, learning from the first experience of ESiWACE.
- To develop collaboration with ICT industry, including co-design, in order to speed up the development of codes for future architectures.

The elaboration of the business model will depend on the results obtained within this first phase of ESiWACE. A first step has been taken by setting up a European HPC Task Force to be complemented by the elaboration of a roadmap.

(7) *Creating communities around specific codes that impact the target sectors, involving ISVs (independent software vendors) where appropriate, and exchange of best practices in particular for SMEs.*

Which codes for what communities? Role of ISVs?

The choice of the ESiWACE science challenge will act as a key focus to create an effective community by providing that community with key information for planning. Also, the support of the following models and tools will further build stronger communities and will help communities adopt tools using best practice:

- The NEMO ocean model used in both climate and seasonal prediction systems;
- The EC-Earth earth system model;
- The OASIS coupler;
- The XIOS IO system;
- The Cylc meta-scheduler also specifically developed for climate and weather applications.

Further, there is a specific activity to develop best practices in terms of performance analysis that will be applied to the ESiWACE science challenge and this will encourage the community to take up new techniques in energy profiling that will be increasingly important as we move to exascale.

There is also the potential to merge two user communities through the merge of OASIS and XIOS leading to a single, stronger community base.

The strength of the communities developed in ESiWACE will be underpinned by the governance work package.

(8) A *governance structure driven by the needs of the users. Commercial management expertise will be needed along with technical expertise to manage industry clients and supply chains, in addition to users from academia.*
CoE should provide pan-European support including to European countries and regions with less HPC-resources
Which governance structure? What and how pan-European support will be made available?

The main challenges for the governance structure within ESiWACE are around:

1. Ensuring that the community are properly informed about the challenges that exascale computing will bring;
2. Recognising, encouraging and exploiting opportunities for shared solution to common problems;
3. Ensuring that work-package R&D and support activities remain user focused.

A one-size-fits-all approach to governance would be ineffective within ESiWACE and hence a flexible approach is being proposed (see the answer to question 1). The governance work package will oversee the governance being applied within the rest of the project and appropriate connections will be made from work packages to the relevant domain specific experts as shown in Figure 2.

The governance work package will be supported by the Scientific Advisory Board (SAB) for high level decision. ESIWACE further relies on a close interaction with the users, cf. response to 1. Supporting user organisations will be invited to participate in workshops, general assemblies, and training activities. In addition, as a quality control measure, the Management Steering Board will interact with representatives of the supporters to assure that project results and services are well disseminated and to evaluate the perceived benefit that ESiWACE generates for the community.

It is safe to assume that with the joint efforts of ECMWF and ENES, a large fraction of the EU community in ESM will be impacted by the innovations from ESIWACE, since all major European institutions are involved with or part of these two organisations. In particular, the developments within ESiWACE will benefit a large weather forecasting community in Europe since ECMWF represents the global medium-range weather forecasting interest of the majority of the European countries.

Besides relying on feedback from weather and climate scientists, ESiWACE will benefit from synergies with the pan-European HPC infrastructure, projects and initiatives, hardware and software industry. This will strengthen the European HPC strategy by developing a specific roadmap for weather and climate simulations. Moreover, among the ESiWACE services we list the investigation into the potential for co-design through involvement (as partners) of hardware-vendors and of a SME providing tools for software development. Through these coordinated efforts, ESiWACE also aims at addressing the skills gap in computational science through support and training of weather and climate scientists.

(9) PRACE has reserved 0.5% of their available computational resources for the HPC CoEs.
How do you plan to use these computational resources?

ESiWACE has requested compute time at BSC/Mare Nostrum 3 and CINECA Marconi to investigate three application cases: (1) Test the porting of the IFS/OpenIFS to Mare Nostrum 3 and continue scalability tests of EC-Earth 2.2, (2) evaluate scalability of the 4 different pieces of coupling software (OASIS3-MCT, ESMF, OpenPalm and YAC), and (3) investigate the hybrid OpenMP/MPI parallelisation and scalability of the ICON software.
A central task of ESIWACE WP3 "Usability" is to give recommendations for an Earth System Modelling software stack to support the exploitation of the pan-European HPC infrastructure in particular PRACE. This work package plans to evaluate the PRACE software stack and to get access to PRACE resources for testing purposes and, even more importantly, to address the PRACE support staff for discussing requirements and limitations of such a domain specific software environment.