Execution of Rolling ACCORD Work Plan 2021

A Consortium for COnvection-scale modelling Research and Development

ACCORD Management Group and Support Team

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1. Executive summary

The present scientific reporting for ACCORD has been prepared by the full Management Group, as a companion document to the Rolling Work Plan for 2021 available here:

http://www.umr-cnrm.fr/accord/IMG/pdf/rwp2021-approved.pdf .

In this first year of ACCORD, an important task for the scientific management was to establish working practices and an organization of the scientific work per Area. In the details, the work organization changes from Area to Area, in an attempt to tailor it closely to the ambitions and needs, while not taking strongly disruptive steps with respect to the existing collaborations from the ALADIN-HIRLAM times. Relevant examples are the establishing of Research and Support Teams inside the upper-air DA Area, with the aim for bringing medium-size teams more closely together and addressing focused topics. Specific Terms of References have been drafted in order to make goals and expectations as explicit as feasible. More specific transversal coordination, on a small number of topics, has also been encouraged in the Surface Area, in parallel to the more general coordination efforts. In System, a new forum of Local Team System Representatives has been proposed, with the aim to provide the ground for building a group of experts and dedicated ACCORD staff involved in code management tools, scripting and other technical subjects. Three Working Groups, transversal to all teams, have been formed and have started their activity for triggering scientific and technical exchange on matters of strategic and raising interest (Machine Learning for NWP codes, Very High Resolution modelling, Physics Interoperability - a fourth one is considered for seamless DA). More details on the organization of the activity in each Area is provided within each Section in this report.

An important overarching goal for the ACCORD management is to enhance interoperability across ACCORD. Interoperability can take various forms and definitions depending on the field of interest. Efforts are ongoing in order to modernize the common working environment and move towards a modern, highly collaborative environment and its associated tools. This effort currently materializes both by modifying the current work practices in the way new T-cycles are being created (more continuous integration process, use of DAVAÏ[1]) and by prototyping a new source code management environment (towards a "forge"). In DA, efforts in order to promote and generalize the use of OOPS-based codes certainly still are in their beginners' phase. Nevertheless, it is expected that the early share of simple tools, the important progress on the side of OOPS-code validation for LAM configurations in the newest T-cycles (eg. CY48T1) and the significant scientific progress with OOPS quite specifically in MF, all are cornerstones on which to build a wider training, testing and use of the OOPS DA codes in our consortium. In Surface, a goal is to increase the scientific exchange on using new SURFEX options in NWP, while generalizing the use of SURFEX in all CSCs is still a work in progress. The WG on Interoperability in the Physics Area has been active throughout the year, and is currently paying particular attention to the needs for code refactoring in specific places of the physics codes. Specialized inquiries have been initiated by the MG towards the teams in order to update the state of art, and better understand needs and expectations, about meteorological quality assurance and system-related practices. One other inquiry deals with the preparation of model outputs and diagnostics.

The overall scientific and technical work in the consortium has been continued with the general spirit that collaboration should progressively evolve from the former A-H situation to the new one with ACCORD. The scientific reporting presented here covers, besides general considerations on organization and management, a number of specific highlights per Area. The MG hopes that this material, though not exhaustive in all details, provides a fair overview of the ongoing activity, and can raise comments or recommendations from the side of the Advisory and Decision-making bodies.

2. Summary of ACCORD activities in 2021 on Management

2.1. Scientific Management and organization of the MG

The Rolling Work Plan (RWP) and the Common Manpower Register (CMR) are important tools for monitoring the consortium R&D activity and the associated resources. The MG has drafted the RWP-2022, the first version for which the MG and the associated co-leads will be fully responsible. Some Area Leaders organized their Area into smaller sub-areas and used co-leads for steering the activity. This splitting was felt needed because of the wide spectrum of topics and expertise, however there usually is no hard border between sub-areas. A change with respect to former practice (in the ALH/HMG-CSSI context) is that all MG members have a direct access to the manpower figures committed and registered by the LTMs, and can interact with them (this possibility was restricted to the consortium PMs in the ALH times).

Beyond these blunt "formal" facts, much of the management and scientific work in ACCORD was about our continued efforts to enhance bridges and practical collaboration across the teams. The MG members have devoted much of their energy to bring the scientists even closer together and encourage cross-family planning and working. Attention was paid to well discuss and agree on the goals, tasks and work practices per Area, and we know this whole process is work in progress for the next months and probably years.

On the side of working arrangements, the MG meets every second Friday (full morning) and Area

1 *definition of DAVAÏ and its content is reminded in Section 3.8 (System), overview of activity*

Leaders also are members of their respective Expert Team of the C-SRNWP program (EUMETNET).

2.2. Information and communication

Our Consortium Scientific Secretary has implemented the ACCORD website, updated the CMR with the new rules for manpower registration adopted in MoU1 and was largely instrumental in the preparations of quite a number of tele-meetings, among which the All Staff Workshop in April (using Bluejeans). The new manpower rules have been explained to the LTMs, along with the evolution of the working practices regarding the RWP and the link with the MG.

Communication within the consortium is done using on-line tools such as “Slack” for short-lived communication, a number of mail-lists for different governance bodies as well as different research and development areas, a dedicated wiki (currently based on the MF/CNRM “Redmine” system) for mid-term archiving of documents and information, and the webpages for long-term and permanent information. The first ACCORD Newsletter is published based on a set of new editorial guidelines, and a focus including code engineering and quality assurance results in addition to the more traditional scientific R&D. The current wiki solution is likely to change later on, depending on choices done at MF and on the evolution of the ACCORD working environment.

Communication about ACCORD outside the consortium mostly was done in the context of the EWGLAM/C-SRNWP annual workshop. The link with ECMWF seems well in place and the new consortium and its staff seem well recognized by both Research staff and management at the Center (this link seems not to have been “eroded” by the new role ACCORD is playing).

2.3. On the edges of the consortium, link with other organizations at a scientific and technical level

Two projects in the close neighbourhood of ACCORD required the attention of the management (the PM and/or the MG, at various levels). The ECMWF/ESA/EUMETSAT co-chaired Destination Earth Program involves the use of the IFS system for a global digital twin of the Earth System, dedicated to the forecasting of weather extremes. It furthermore includes an on-demand LAM digital twin, at hyper-resolution (hectometric) scales, dedicated to specific, user-driven extreme events forecasting. Destination Earth is a European Commission funded program. The on-demand LAM will be procured by ECMWF, who is expected to publish the Call for Application before the end of this year (the exact timing has shifted several times). The PM has participated in several Member State meetings and discussions with P. Bauer. The ACCORD PAC, and then STAC, formed WGs with the aim of drafting a sound set of recommendations about what an ACCORD-based proposal could contain (in phase 1) and how an ACCORD-based DestinE partnership could form and interact with ACCORD itself. On the scientific and technical level, the main topics that would fall in the scope of our NWP consortium are code adaptation to mixed CPU-GPU, modelling at ultra-high resolution (including use of observations and perhaps data assimilation), post-processing and linking with impact models. The STAC WG paid special attention to the balance between ambition and realism, when formulating its recommendations.

The HIRLAM and the UWC consortia have started a common analysis effort for preparing the transition from the “HIRLAM situation” to the “ACCORD+UWC situation”. The major issue in this transition, for the HIRLAM and UWC groups, is to well understand and design the research-to-operation interfaces, taking into account the specific working arrangements that these groups want to have (and that certainly will be different from those between research and operations in other ACCORD partner institutes). At the level of ACCORD, the MG has started its own analysis of how the research-to-operations interface could be seen from the perspective of the new 26 member consortium. This analysis will continue over the 2021-2022 winter.

3. Activity report per Area

3.1. Strategic program: Transversal software developments (SPTR1)

- ***overview of the activity in the area***

The registered manpower during the first six months of 2021 for this work package amounts to a total of 16 person months, which is more than half of what was foreseen for the entire year 2021 (24 person months). Of these 16 person months, 9 person months relate to research and development, 4 to management activities (mainly organizing and attending meetings, both inside ACCORD and with ECMWF), and 3 to training.
From the topics indicated in the manpower registration, it becomes clear that the focus of the work carried out in this work package lies almost entirely on the preparation of the ACCORD codes for heterogeneous hardware platforms (Task SPTR1.3), while work on other tasks has stalled (SPTR1.1: Atlas; SPTR1.2: MultIO server; SPTR1.4: training). Increased attention will be devoted to these tasks in the upcoming months.

The activities on preparing ACCORD codes for heterogeneous hardware can be categorized into the following subcategories:

- porting of parts of the ACCORD code to GPU;
- development of tools that perform a source-to-source transformation of the existing ACCORD code into code that is suitable for running on GPU;
- adaptation of control routines and data structures.

Porting of pieces of the ACCORD codes to GPU

Still very much in an exploratory phase, different approaches have been investigated to make pieces of the ACCORD codes run on GPU's. For instance, the biFourier spectral transforms have been ported using the FFT's that are part of NVidia's CUDA library. By eliminating unnecessary intermediate communications between the host (CPU) and the device (GPU), a very significant speedup was achieved. While the use of CUDA is acceptable for a piece of code that doesn't change much over time (such as the spectral transforms), using CUDA for parts that are under continuous scientific development (such as the physics parameterizations) is not appropriate: we cannot expect all scientists inside ACCORD to learn CUDA and start developing the model using CUDA functionalities. Moreover, CUDA is a proprietary library of NVIDIA, which may not work on other accelerator hardware such as AMD GPU's. For these reasons, a different approach is taken for the physics parameterizations, namely the use of (OpenACC) directives.

The porting to GPU of several physics parameterizations has also been investigated; ACPCMT (deep convection), ACTKE (turbulence), ACRANEB2 (radiation). Several porting strategies have been considered. One such strategy is to make the piece of code (kernel) to be offloaded to the GPU in a single go as large as possible; in this case that would come down to the entire parameterization. The advantage of this approach is that the amount of OpenACC directives is quite limited (basically, only at the top-level where the parameterization is called). On the other extreme end, one could take an approach where many small kernels are defined (basically around each horizontal loop in the code). While less attractive in the sense that this approach will require many more OpenACC directives, it turns out that it may be significantly better in terms of performance, at least on the hardware that was used so far (NVIDIA V100 GPU's) and with the compiler version used. Also other aspects such as the loop order may have a dramatic impact on the performance.

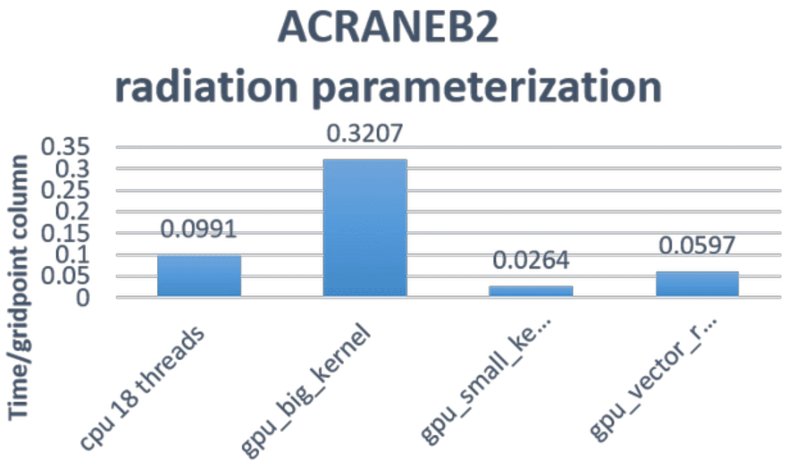


Figure 3.1.1. Comparison of performance of acraneb2 radiation scheme ported to GPU using different strategies

The figure above shows some timing results obtained with different strategies to port the ACRANEB2 radiation scheme to GPU's. In this specific case, the optimal strategy turns out to be using small kernels and putting vertical loops inside horizontal loops. However, the important phrase in the previous sentence is probably "in this specific case"', since the optimal strategy will depend on the hardware architecture, on the compiler and on the application. So rather than choosing one strategy and applying it to all the physics parameterizations inside the ACCORD CSC's, this kind of testing will need to be repeated for the other parameterizations, and for other hardware platforms. In order to be able to carry out this testing efficiently, we should rely on tools that are capable of automatically performing code transformations such as loop interchanging, annotating with accelerator directives, etc.

Source-to-source transformation tool

As indicated in the previous section, in order to be able to run the ACCORD model efficiently on various hardware architectures, it is necessary to develop tools that are able to transform the original (CPU-optimized) source code into a target-specific variant. This idea is not new, and other consortia and institutions have been developing such tools before. The usability of some of these tools for the ACCORD codes has been investigated. A first such tool is CLAW, developed in the COSMO consortium. While impressive results have been obtained with CLAW inside COSMO, it turns out not to be suited very well for the NPROMA-blocked layout that is used in the ACCORD codes, and it also doesn't handle deeply nested routines appropriately.

A second tool that is being investigated is LOKI, developed by ECMWF. Being still in an early development stage, some functionalities are currently still missing to make the full source code transformations that are needed to port physics parameterizations to GPU's.

Finally, some custom (perl) scripts have been developed to perform the necessary source code transformations such as loop interchanging, subroutine inlining, adding/removing array dimensions, etc. These tools are capable of transforming the CPU-optimized version of the ACRANEB2 scheme into a GPU-targeted version automatically. Whether these tools also suffice for the other parameterizations will be explored in the near future.

Adaptation of routines and data structures

While work on individual pieces of code, as described before, is useful in itself, there is also a challenge in putting these pieces back together. For example, when running on a CPU, it is advantageous to split the work into smaller NPROMA-blocks, in order to reduce the memory footprint, and improve cache efficiency. However, on a GPU it is important to expose as much parallelism as possible, and treating the different NPROMA-blocks one-by-one will not lead to good performance. On top of that, the user may want to run some parameterizations on an accelerator (not necessarily GPU), while other parameterizations remain on the CPU. To deal with such a situation, a very flexible code is required where the choice for the parallelization model (OpenMP/OpenACC/vector/…) is made at the level where the parameterizations are called (i.e. routines APLPAR/APL_AROME in the ACCORD code), instead of at the higher

level where it is made now (routine CPG_DRV). The dataflow between the parameterizations, which currently relies on raw Fortran arrays, should be organized with smart data structures that are able to keep track of the context (e.g. allocation status on CPU host and accelerator device).
ECMWF has already made significant progress in restructuring their physics parameterization calls and using smart data structures for the dataflow. Work has started to also adopt these data structures for the ACCORD physics parameterizations.

- ***organisation of the work within the consortium***

Work is organized through regular online meetings, to which also area leaders of related work packages (Dynamics, System) and CSC leaders are invited. Initially, an in-person kick-off meeting was foreseen, but this turned out to be impossible given the COVID-19 pandemia. Also stays abroad have been postponed for this reason.
Information is shared through the wiki pages of the work package.

- ***highlights from 2021***

One specific highlight of 2021 was the participation of an ACCORD team in the IDRIS GPU hackathon. During this week, several parts of the ACCORD code were ported and optimized to GPU's, under the guidance of NVIDIA experts. Probably even more important than the direct result in terms of ported code, this hackathon allowed ACCORD participants to gain knowhow and experience with GPU compilers, debuggers and profiling tools. Given this positive experience, the aim should be to participate in similar future events which will be organized in the framework of EuroHPC.

- ***perspectives and priorities for 2022***

For 2022, the ongoing activities will continue:
  - porting of more individual parameterizations;
  - further testing and development of source-to-source transformation tools, considering both LOKI and custom scripts;
  - restructuring of the dataflow in the upper-level control routines and integration of the ported parameterizations in the full ACCORD model

On top of that, increased attention will be given to the tasks in SPTR1 that are delayed due to a lack of manpower in 2021. New staff has been hired at MetNo, and hopefully more staff will become available through DestinE-Extreme to speed up the progress in this work package.

3.2. Dynamics (DY1 to DY3)

- ***overview of the activity in the area***

On the dynamics side, the most important work has been on developments to increase the stability of the current semi-implicit (SI) and semi-Lagrangian (SL) spectral dynamical core. The development of a grid point model has also been pursued, and a branch is available in which the implicit system is solved efficiently in grid point space.
Activities around the new Finite-Volume Model (FVM) are delayed as we await a new branch by ECMWF with the latest developments. The new DestinE project has also had a significant negative impact on the previously defined work plan, as a significant portion of our work time is devoted to planning the development of this new operational system.

- ***organisation of the work within the consortium***

Many countries contribute to this activity. CHMI and SHMU collaborate on various theoretical aspects, including the promising topic DY1.5. Météo-France is also very active in the development of new solutions in the spectral model to increase stability but also in the context of new developments (DY1.3). The Hirlam-family teams are active in the field of very high resolution modeling in which they are largely involved. Meetings have been organized, currently the DestinE meetings have taken over from the former meetings.

- ***highlights from 2021***

Three activities with important results are highlighted for this year:

➢ DY1.5 : Currently, the hydrostatic (HY) and the fully compressible nonhydrostatic (NH) systems of equations, along with their numerical discrete integration forms, are two fairly separated dynamical cores and codes. The aim of this topic is to reformulate the compressible nonhydrostatic system of equations as a departure from the hydrostatic system which may be controlled through a new parameter ε (ε = 1 NH core, ε = 0 HY core). Then all computations of the dynamical core can be treated in a unified code. Moreover, this parameter ε can be vertically dependent. It would allow us to suppress the nonhydrostatic assumption close to the model top where the vertical resolution is too coarse to properly sample NH processes.
Status: A set of (6) control parameters was introduced in the full Euler system of equations in order to separately control each nonhydrostatic term. If all the parameters are set to 0, the system collapses to the hydrostatic primitive equations, while setting all parameters to 1 gives the Euler equations. These control parameters may actually be defined independently both in the linear (SI) part and in the nonlinear part, as used in the SI non-iterative or iterative time schemes.
An idealized linear space-continuous stability analysis was performed at first, which showed the regions of stability for distinct choices of control parameters. The analysis indicated which values of the control parameters may possibly have a stabilization effect on the integration scheme. For instance, it was shown that values slightly higher than 1 in the linear model are beneficial for stability while values smaller than 1 are destructive.
The experimental studies run so far encompass idealized experiments with the vertical slice 2D model, as well as real simulations for two datasets. The first case corresponds to the Czech operational setting and the Czech operational domain with a grid mesh of 2.325 km, dynamical adaptation, for a case of strong wind over Krušné Hory from 12 February 2019 00 UTC integrated for 24 hours. We obtain very good correspondence between results of the stability analysis and the model behaviour found in the real simulation. Hence, we are able to enhance the stability of the model time scheme through the change of the control parameters. The time scheme used in this case is two-time-level non-iterative SI extrapolating along the SL trajectory (SETTLS). The obtained results were qualitatively compared with a given reference. We may say that the basic NH features are captured by the model with "reasonable" values of control parameters. For values differing significantly from 1, a deterioration of results is observed. The second simulation was run for the Occitania domain in 375m horizontal resolution and modified settings of physics. In this case, the modification of control parameters in the linear model only was not enough to ensure stability and we had to modify the control parameters in both the linear and the full model. The larger the timestep is the smaller the control parameters must be (and hence the further the modified model will be from the full NH system).

➢ DY1.8 :
1 hour coupling frequency is believed to be an interesting option, but the current LBC files prepared from ARPEGE for the LACE domain are "huge" while our HPCs are "fast". It follows that we are not able to get the LBC files quickly enough to use them operationally in high frequency (1h). We might think of implementing frames in FA format and/or considering connected problems (like LBC transformed to grid point space, the central part removed and just the frame distributed, central values smoothly completed, the whole field bi-periodized and transformed to the spectral space). Such a procedure must reasonably precisely keep the values in the coupling zone. We would like to start to design such frames and to test them. These activities must be strongly coordinated with our partners, mainly Météo France, as the producer of LBC files for several ACCORD teams.

➢ DY1.3 :

One ongoing work is to improve the current semi-implicit, semi-lagrangian, spectral transforms system. Modifications imply the development of new options :

- NVDVAR = 5: this is the introduction of a new couple of vertical momentum prognostic variables (W, d5). W is by construction less sensitive to the effect of the terrain slopes since the rigid bottom boundary condition turns into ($W_{surf} = 0$), and d5 is a new pseudo-vertical divergence variable derived from W so that it minimizes the size of the non-linear residual terms in the NH pressure departure prognostic equation. Stability studies as shown in Figure 3.2.1 suggest an enhanced stability using these new variables.
- LREFINE_SILAPL: this option is a refined formulation of the discrete vertical Laplacian-like operator involved in the semi-implicit linear models. This new formulation takes into account the extra coupling between (d4 or d5) and the NH pressure departure variable induced by the presence of orographic metric terms introduced by the terrain-following transformation.
- SIPRA: introduction of an extra SI parameter for hydrostatic surface pressure in order to stabilize the model above very high orography (e.g, Himalaya, Andes,...) where the amplitude of the baric non-linear residual terms starts to be dramatically significant. Proof already was provided that this option improves stability on an idealized 3D case with no wind and no diffusion. At very high resolution, the model is stable with this new option, whereas the current system is not.

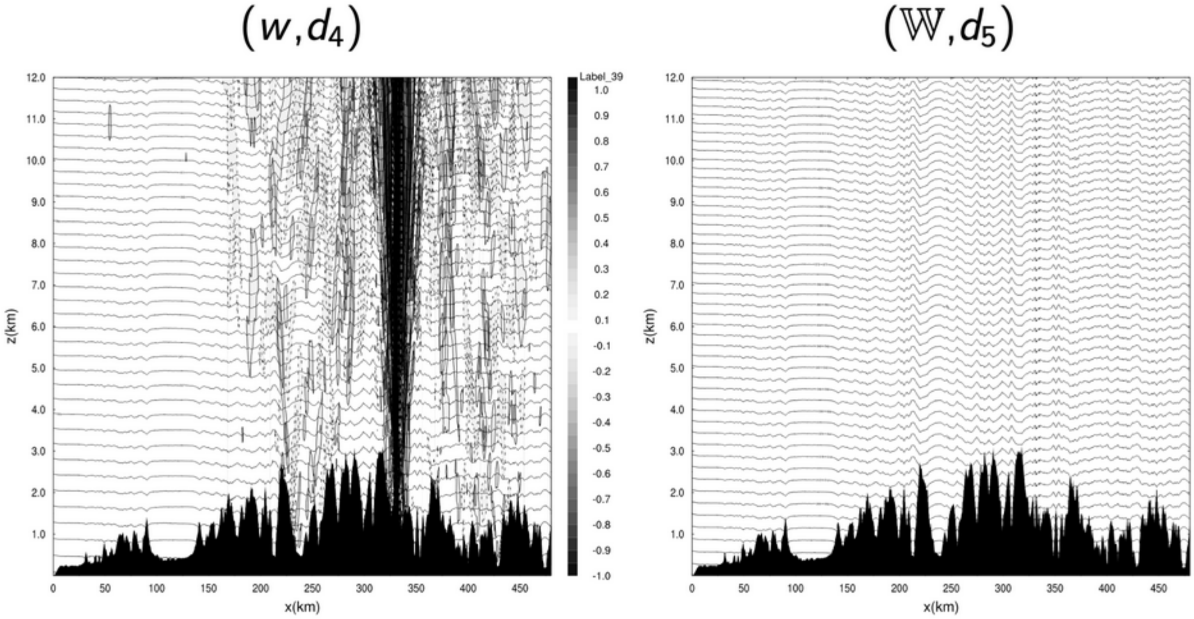


Figure 3.2.1. Idealized test case (no wind, no diffusion, prescribed temperature), but with a realistic orography of new prognostic variables (right) compared to old ones (left). The new proposed variables exhibit a better pattern.

- ***perspectives and priorities for 2022***

For 2022, the current activities will continue, especially further testing of more stable options (both DY1.3 and DY1.5). The goal will be to assess the improvement on realistic problems encountered such as the degradation of scores over large North-American domains, and for very high resolution configurations.

The action regarding the use of FVM and its adaptation and testing in a LAM context, which was not very active in 2021 due to the delay in the provision of the code by ECMWF, should start next year.

Concerning the current developments for removing the spectral transforms, work should be pursued, additional manpower would however be needed on that topic.

3.3. Data Assimilation (DA1 to DA8)

- ***overview of the activity in the area***

During the first semester of 2021, a total of 226.75 person months (20.61 FTE) was reported as contribution to data assimilation (DA) work, which is 47.9% of all expected. The largest part (23.3%, 4.8 FTE) was a contribution to the implementation of new observation types (DA4) (Fig. 3.3.1). The second largest (22.8%, 4.7 FTE) was on the improvement of the assimilation or implementation of the known and existing observations in our operational DA system (DA3). 15% (3 FTE) of the reported contribution was on the implementation of the DA system in member states with no local DA (DAsKIT). Work towards development of the operational 3D-Var system (DA1), flow-dependent DA systems (DA2), and DA for nowcasting application (DA5) was, respectively, 10.6% (2.1 FTE), 10.4% (2.1 FTE), and 7.7% (1.6 FTE) of the reported contributions. The reported contribution for OOPS development is small (3.5%, 0.7 FTE), but it is hoped to increase in the future, as a follow-on of main achievements at Météo-France and of recent progress in other ACCORD contexts. Only 6.7% of the contribution was attributed to implementation and development of observation pre-processing, system diagnostic, monitoring and verification tools (DA7). It's worth mentioning that work attributed to development of the nowcasting system could be more than 7.7%, since it can be included in both DA2 and DA3.

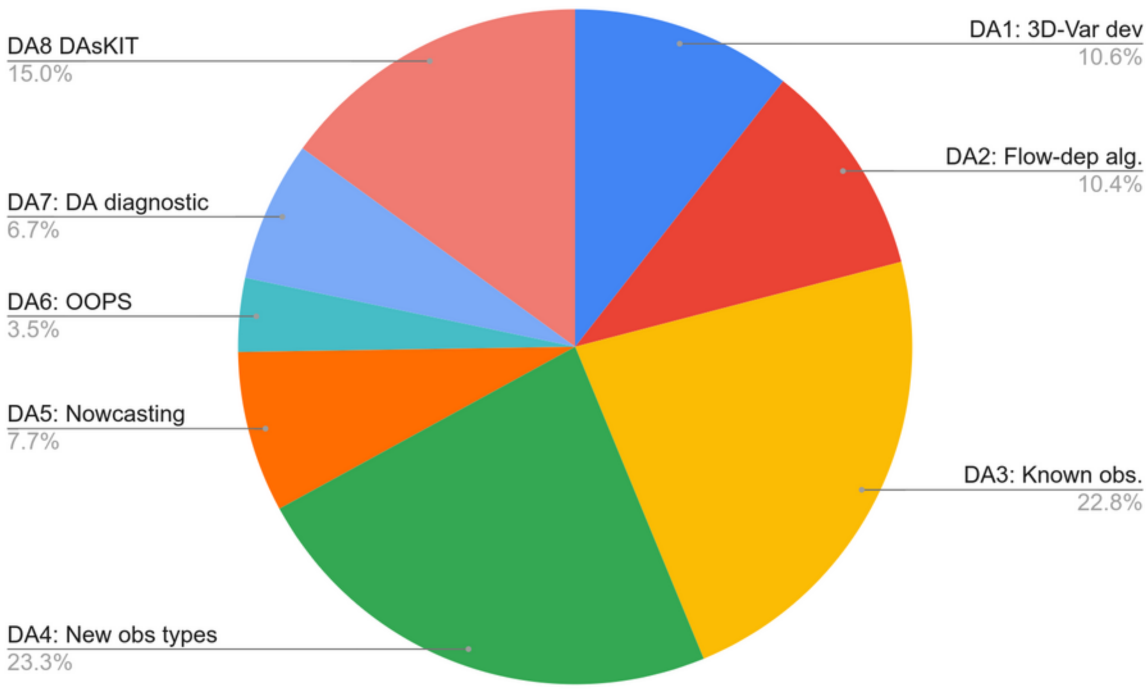


Figure 3.3.1. The reported DA work during the first semester per work package.

- ***organisation of the work within the consortium***

As shown above, the DA tasks are described in 8 work packages which accomplishment is handled by two groups of research and support teams. 13 research and 9 support teams were formed. Research teams are in charge of tasks which involve code development (e.g. DA2, DA4, DA5, DA6, and DA7). In support teams, the members help each other to locally implement known and existing in the system observations and available solutions. The teams' tasks discussions are led by a Chair or co-Chairs. Most of the teams agreed to meet virtually and in person minimum twice per year. It is expected that the research teams meet at least once per year in person, while the support teams are expected to meet once per year. More about the DA teams and the respective tasks can be found on the ACCORD wiki page (https://opensource.umr-cnrm.fr/projects/accord/wiki/Data_Assimilation)

- ***WG: Seamless Data Assimilation VHR-DA for NWP and Nowcasting (DA-SEAM)***

The MG proposed to form a specific WG in order to discuss the options for seamless DA systems suitable from the nowcasting to the NWP ranges. In addition, considerations on very high resolution applications should be part of this WG. This activity has not yet started.

- ***highlights from 2021***

We progressed well with the majority of the planned tasks in 2021 although some of them couldn't yet start due to different reasons. The ongoing works can be summarised briefly as follows:

- ➢ Smooth migration to higher cycle (CY43) was successful at most member states and collaborating operational groups. The ensemble data assimilation (EDA) systems have been ported on the new Météo France HPC (DA1).
- ➢ We succeeded to explore further the available solutions which aim at improving the performance of the DA algorithms such as increased vertical resolution (60 to 90 levels), different ways of computing the background error statistics (EDA, Brand) and initialisation procedures (incremental analysis update (IAU), cloud initialisation) (DA1/DA2/DA5).
- ➢ The possibility of using the operational ensemble DA for the AROME 3DEnVar system has been experimented with promising results at Météo France, using EDA with observation perturbations and SPPT. An EDA approach with observation perturbations and surface perturbations has also been investigated in MetCoOp for computing the climatological B (DA2).
- ➢ Accounting for the large scale information in ("classical" Jk or pre-mixed penalty-free Jk) or prior to (LSMIXBC) the assimilation process was evaluated with good and promising results (DA1).
- ➢ A multi-resolution incremental 4D-Var assimilation scheme was further developed, tested and made available for daily run in an operational environment with all known and operationally used observations (*Barkmeijer et al., 2021*) (*Fig 3.3.2*). The scheme is also under exploration for use in the nowcasting regime (DA2).

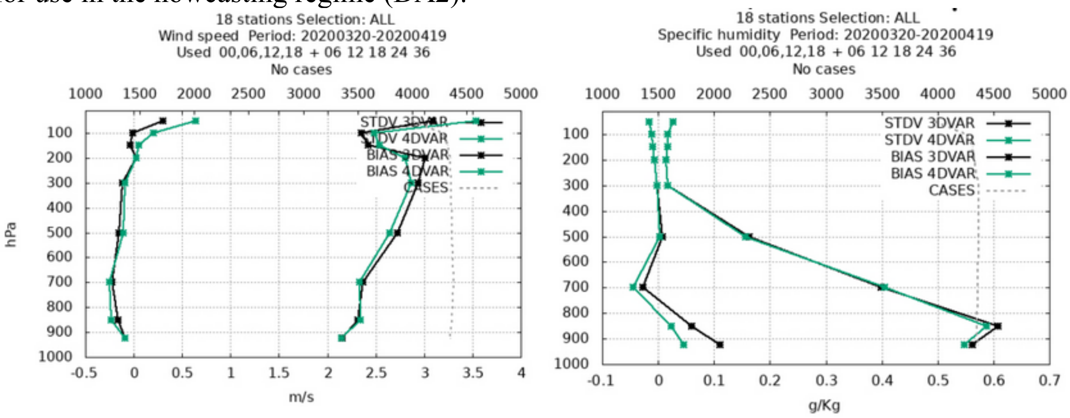


Figure 3.3.2. Bias and standard deviation for wind speed (left) and specific humidity (right) forecasts in experiments with 3D-Var (black) and 4D-Var (green) assimilation schemes. The experiments were performed with the MetCoOp model.

- ➢ The Harmonie version of the hybridEnVar was further developed and tested with Brand initial perturbation and compared with different ensemble assimilation techniques (EDA, BRAND, BREND) (DA2).
- ➢ The 3D-Var minimisation in OOPS-AROME was successfully validated in CY46T1 at Météo-France, by careful comparison with the current "masterodb" version. Progress has also been achieved in first tests and implementations of OOPS 3D-Var in ALARO and HARMONIE contexts.
- ➢ Using this OOPS framework, 3DEnVar and 4DEnVar have been successfully developed and evaluated at Météo France (DA2/DA6). The 3DEnVar scheme is proved to be significantly better than 3D-Var (Fig. 3.3.3), so 3DEnVar is planned for a double E-suite at Météo-France in 2022. Moreover, 4DEnVar using 4D-IAU, and the same observations as in 3DEnVar, is proved to be superior to 3DEnVar. These 4DEnVar experiments will be pursued with frequent observations (15 minutes). Testing of extended (hydrometeors) control variables has also started using the AROME-France 3DEnVar.
- ➢ Intensive testing of settings capable for nowcasting application is ongoing in MetCoOp (rapid refresh), at DMI (RUC - rapid update cycling) and at ARSO (RUC). This consists of testing frequent and high resolution observations (radar, GNSS-ZTD, Mode-S, AMV, T2m, Hu2m

from Netatmo). A common feature between old and new experiments pointing to improvement and remaining challenges in handling/predicting of “dry” (ex. Temperature improvement in 1 hour cycling) and “wet” (ex. Humidity and precipitation, improvement in 3 hours cycling) fields were observed in the systems using RUC. A framework for exploring sub-hourly DA cycling is being built on model and scripting levels (DA5).

➢ The variational constraint (VA) was ported to CY43 and porting of Field alignment is ongoing (DA5).

➢ The assimilation of radiance data is being improved through 1) appropriate update of the coefficients used in the variational bias correction scheme; 2) improved assimilation of low peaking channels from microwave instruments; and 3) corrected (by adding more passively assimilated important channels) cloud detection scheme for IASI (DA3).

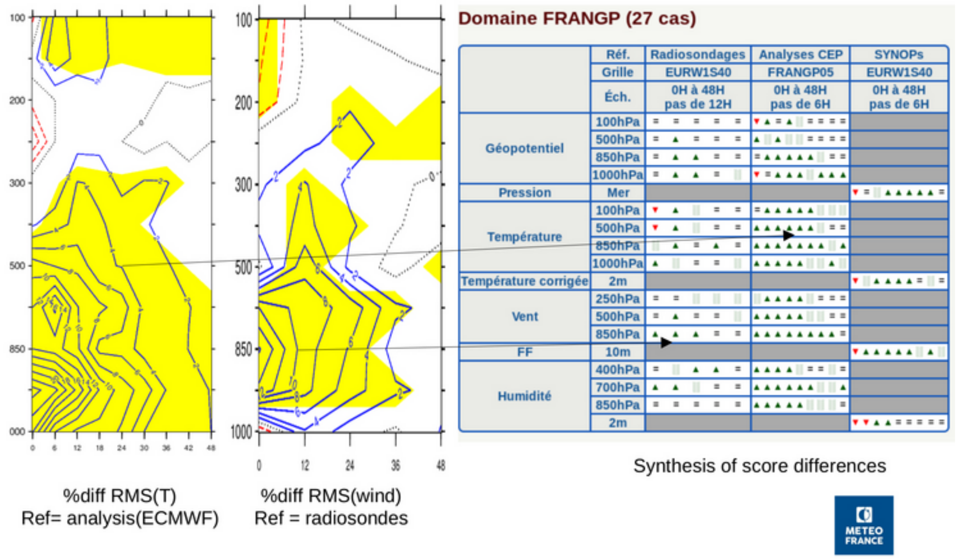


Figure 3.3.3. Verification scores comparing the 3D-Var and 3DEnVar assimilation schemes. Blue lines and yellow colour means significant reduction of forecast errors for the run with 3DEnVar compared to that with 3D-Var. The experiments were performed with the AROME-France model.

➢ The radar data assimilation was further tuned, with promising results at AEMET (Doppler wind), and with modifications included in the current E-suite at Meteo France (French and OPERA radars : doppler wind and reflectivity data).. Further, performance of the radar reflectivity operator in combination with ALARO physics was evaluated through impact study at ARSO and CHMI. Furthermore, dealiasing methods for Doppler winds were intercompared at ARSO and torus mapping method was selected for implementation into the HOOF preprocessing tool. Similarly to what was implemented in PrepOpera, a superobbing approach was also implemented in HOOF (DA3).

➢ Appropriate assimilation of low resolution observations with footprint and supermodding observation operator was developed for scatterometer data (*Mile et al. 2021*). Extension of this technique to other remote sensing observations (Aeolus L2 HLOS winds and radiance observations) is ongoing (DA1).

➢ Many operational assimilation systems were enhanced through augmented use of different observations (increased use of radiance data (ATMS, IASI, MWHS-2, SEVIRI), Scatterometer, GNSS-RO, AMV, high-resolution BUFR-formatted radiosonde, …) (*Lindskog et al., 2021*) (DA3).

➢ We have good progress in implementing new types observations, including relevant quality control also involving machine learning techniques (all-sky radiance, Scatterometer data from new satellite, Aeolus L2 HLOS winds (*Hagelin et al., 2021*), GNSS slant delay, high resolution surface pressure from private stations (Netatmo) and smartphones (Figure 3.3.4), observation from attenuation in telecommunication microwave links due to rain, and radar polarimetric data) in our assimilation systems (3D-Var, 3DEnVar) (DA4).

➢ DAsKIT members progressed well with the implementation of the surface DA, computation of the background error statistics for the variational upper-air system, and more observation types handling, as well as building of new modules in ecflow-driven NodeRunner system

(DA8).

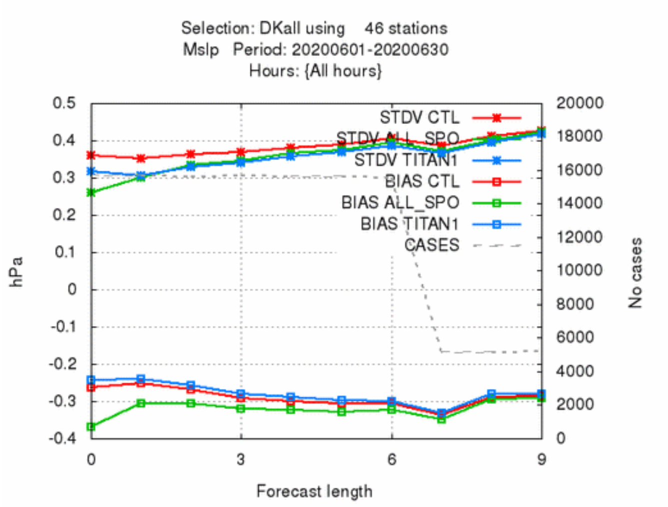


Figure 3.3.4. Standard deviation and bias for mean sea level pressure forecasts as function of forecast range for three runs: the control experiment (red) without smartphone pressure observations (SPOs), experiment with all SPOs and no QC (green), and experiment with SPOs quality controlled with TITAN (blue). Note that the experiments were performed in a Harmonie-AROME model at 750m horizontal resolution at DMI.

- ***perspectives and priorities for 2022***

The following tasks will have special attention in 2022:

- ➢ Consider flow-dependent (4D-Var or 3DEnVar) DA schemes for operational application, if possible under OOPS framework (DA2/DA6).
- ➢ Pursue development and experimentation of 4DEnVar under the OOPS framework with frequent observations (15 minutes) (DA6).
- ➢ Ensure that ongoing progress is pursued on OOPS implementations of data assimilation (DA6).
- ➢ Continue exploring DA procedures, settings, and frameworks (for example sub-hourly DA) appropriate for nowcasting applications (DA1/DA2/DA3/DA5).
- ➢ Continue exploring DA schemes and methods appropriate for handling and initialisation of hydrometeors (OOPS-EnVar) (DA2/DA6).
- ➢ Continue exploring more observations for DA by accounting (using superobbing, supermodding, footprint operators) their effective resolutions (DA1).
- ➢ Continue exploitation of alternative observation (personal weather stations, smartphones, microlinks, etc …) by paying attention to relevant quality control techniques, including machine learning (DA2/DA4).
- ➢ Prepare for assimilation of more relevant new satellite products (DA4).
- ➢ Continue supporting the “catching-up” implementation process by DAsKIT members (DA8).

3.4. Physics parameterizations (PH1 to PH10)

- ***Transversal activities and WG on Physics Interoperability***

Several work packages in the Physics Area are managed in a transversal manner, with the aim of taking the needs or specificities of each CSC into account when relevant.

The group sharing work on the common Single Column Model configuration (MUSC, PH4) intends to prepare a common (to all CSCs) MUSC version based on CY46T1, which will be validated on a number of agreed test cases. A WW will take place in November (at FMI) for this purpose.

For PH5, about model outputs and diagnostics, a new consortium-wide inquiry has been launched in order to establish an updated list of the developments, plans or wishes expressed by the teams. The inquiry was prepared by the PM with the CSC Leaders and CNA, who will together analyze the answers and propose a work plan (avoiding duplicates, proposing coordinated efforts where this seems relevant, otherwise sharing information on who does what, provide support when felt needed).

The group on cloud-aerosol-radiation interactions has met twice by tele-meetings in 2021 (PH6). The basic decision was to use CAMS near real time aerosol information, and to provide infrastructure enabling its exploitation in all ACCORD CSCs. Ideally, this design should be general enough in order to make possible the future use of alternative aerosol data (e.g. from MOCAGE). Attention will be paid to also enable the use of CAMS aerosol climatology via traditional monthly climate files. The work was progressing continuously this year, based on the efforts of local staff from the most involved teams and despite the impossibility to meet physically. An overview of the intended strategy of development, along with recent results, has been presented at the EWGLAM-2021 workshop (L. Rontu, D. Martin Pérez and Y. Seity). Taken from this presentation, the table below sketches the workflow and the aerosol characteristic input data for CAMS in either climatological or near real time mode.

CAMS data type	**climatological data**	**near real time data (NRT)**
resolution (horizontal)	2.5 deg * 2.5 deg	0.5 deg * 0.5 deg
geometry	2D	2D or 3D
mass mixing ratio (MMR)	NR = 11 species	NR = 14 species
IOP: ME, SSA, ASY (for NR species)	for sets of 14 shortwave and 16 long wave wavelengths	same 14 SW and 16 LW wavelengths
Relative Humidity	IFS forecast	IFS forecast
expected interaction in NWP model	radiation	radiation & cloud microphysics
generation in NWP workflow	during climate file computation	interpolated and provided via coupling files

Table 3.4.1. Current and suggested use of CAMS aerosol data in ACCORD models. Explanations about the abbreviations: IOP stands for Inherent Optical Properties, ME for Mass Extinction, SSA for Single Scattering Albedo, ASY for Asymmetry Factor. These IOPs are functions of wavelength, humidity and aerosol species.

The impact of using NRT aerosol information in an ACCORD model is illustrated in the figure below, which shows the sensitivity of the SW downward radiation flux for one single Harmonie-Arome forecast (5 Feb. 2021, 00 UTC run)

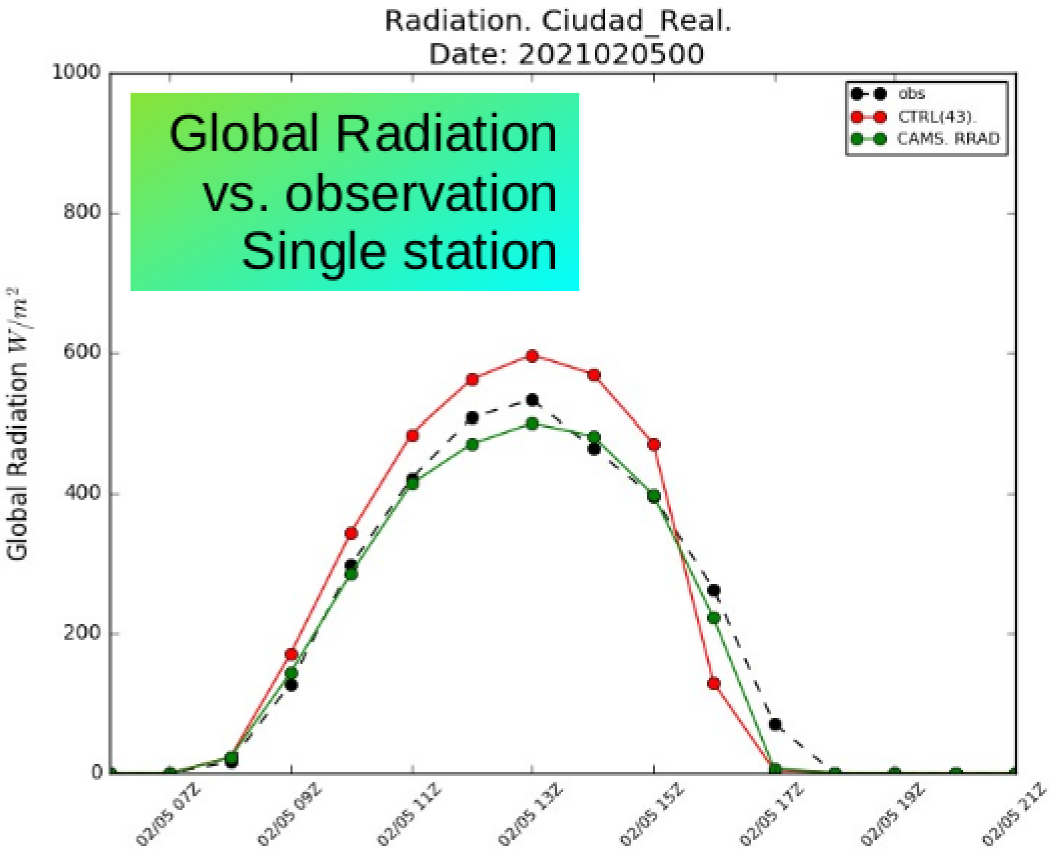


Figure 3.4.2. Compared SW downward radiation fluxes from a single-day Harmonie-Arome forecast. The black curve shows the observed values at the location of Ciudad Real, the red curve is Harmonie-Arome CY43 (using the Tegen aerosol climatology) and the green curve is using CAMS NRT values. Courtesy by D. Martin Pérez, L. Rontu and Y. Seity.

Work on 3D effects in physics parameterizations (PH7) currently is mostly triggered by the teams in MF (turbulence) and DMI (radiation). For turbulence, several ideas are proposed for taking into account horizontal mixing in specific conditions, one by extending the TKE 1D formulation in presence of shear-induced production terms (thought to be relevant for instance for flow over mountains) and another one by adding turbulence terms for increasing mixing in the shallow convection formulation (for cases of convective boundary layers). Code for implementing the horizontal gradient terms necessary for a 3D turbulence parameterization, within the SISL-ST time step organization of the Arpege-Accord models, has been largely integrated in CY48T1. This opens the possibility for preliminary tests in 2022 and then beyond. 3D effects in radiation will be studied in Harmonie-Arome (shadowing and/or mean effects of lateral fluxes in a multi-grid approach).

The use of stochastic thinking within physics parameterizations (PH10) is a core part of a PhD work that started in the autumn 2020 at MF. In SHMU a very high resolution (375m) version of ALARO was run and the output was used to feed an AI algorithm in order to build it in the forecast model to improve the wind and wind gust forecast in high wind conditions.

The specific work on interoperability across the CSC physics packages is the core topic of WP PH9. The group active in PH6 has drafted a technical document describing the interoperability targets for the cloud-aerosol-radiation developments, and takes those recommendations onboard of its own future work.

The Physics Interoperability WG, adopted at the 8 March ACCORD Assembly as an answer to the absence of a Physics Area Leader, has started to work in early spring 2021. Several proposals regarding the physics-dynamics interface (i.e. consistency of specific terms in the equations) have been discussed and are now being drafted in the RWP-2022. These topics usually require the involvement of experts of both dynamics and physics equations.

The main item discussed in the WG is the complexity of the physics parameterization interface code (two routines that go after the names “APLPAR” and “APL_AROME”). The WG is reaching a conclusion that these interfaces should be re-factored in order to make them simpler, which will enable newcomers to use them more easily and experts to proceed with an elaborated analysis of the lower level interfaces (to the individual parametrization codes). The re-factoring could include a splitting of the APL* routines themselves, in order to have one much simpler version per CSC. This splitting would be complemented by a careful analysis of all interfaces and data structures, with the aim to design interfaces that will be shared by all CSC physics packages in the ACCORD future codes. Quite remarkably, or strikingly, a very similar analysis will be needed for preparing the physics code packages to hybrid HPC architectures (e.g. CPU-GPU). Thus there is a clear link with SPTR1.

Some specific information meetings have started on the initiative of the WG, with teams in ACCORD, in order to start explaining the WG's current vision ahead of any complete drafting of a roadmap. The roadmap, describing the proposal for enhancing the physics interoperability, still is expected to be ready by the end of 2022.

- ***Short summary of highlights for 2021 per CSC***

➢ **AROME**

For the Arome atmospheric physics several aspects are investigated:

- fog with the field campaign SoFog3D (PhD thesis Salomé Antoine). Several sensitivity studies have been performed: increase of the horizontal (500m) and vertical resolution (156) with a first level at 1m, comparison between the operational one-moment scheme (ICE3) and the new two-moments scheme LIMA, evaluation of additional processes such as a liquid water term for deposition from the first level above the surface and/or a subgrid condensation term. The results are encouraging especially for the hectometric configuration associated with the finest vertical grid, however some delays are observed for the formation and dissipation phases (more details in the ACCORD Newsletter pp. 107-110 and in §3.9 on the very high resolution modelling WP HR1)
- over estimation of low clouds over the Mediterranean sea. In some situations, AROME-France overestimates low clouds near the sea surface. This overestimation (less present in ARPEGE) is not reduced with the assimilation cycle due to the lack of observations over sea for the boundary layer. Many experiments (modification in the shallow convection, mixing length, tuning parameters) have been carried out with AROME and with the ARPEGE physics on the AROME grid without success. However, the way the turbulence tendencies on the conservative variables are being used, especially for cloud variables, seems to play an important role in this situation.
- EcRad is now "almost" available in cy46t1 with some updates. Preliminary tests have been performed for two one month periods with neutral or slightly positive impact and without additional computational cost. Within EcRad, several options are available with potential positive impact such as: new aerosols and ozone climatologies, cloud optical properties, SPARTACUS (more expensive) .. those options will be evaluated in AROME and in ARPEGE.
- A very important necessary step has been achieved for the use of the 3D turbulence in AROME. Since cy48, the horizontal gradients computed in the semi-lagrangian scheme are available in APL_AROME. The next step will be to implement in the turbulence scheme the approach of Göger et al (2018), which is very important for complex terrain. However, for a full 3D turbulence scheme, the horizontal divergence of the turbulence flux cannot be computed inside the physics with this code version (more details in the WGNE blue book 2021, by Honnert and El Khatib). This work is shared with PH7.1

For the next operational AROME system based on cy46t1op1, all the AROME configurations (France and the five overseas domains) will use ECUME V6, with exactly the same options for the atmospheric physics and for the dynamics, ie with COMAD, no SLHD and linear interpolators in the semi-lagrangian scheme.

➢ **ALARO**

The turbulence scheme TOUCANS has multiple options for computation of turbulent fluxes of momentum, heat, water vapour and cloud condensed water and the effects of shallow convection.

Further validation is being done to profit from many available options and to update the selected set-up used by the operational applications. The work continued on implementation of TKE-based mixing length in TOUCANS. The effects of water phase changes in the shallow convection, causing density fluctuations, are taken into account by a parameterization of the moist buoyancy flux. The numerical treatment of the two turbulent energy schemes was adapted to avoid occasional shifts in vertical profiles.

The work on the radiation scheme can be extended to 3D. Climatological aerosol optical properties can be replaced with those (daily) provided by Copernicus Atmosphere Monitoring Service (CAMS MACC products). This work is shared with PH6.

So far, a single precision version of the externalized single-column ACRANEB2 version was prepared and critical parts causing blow-up at high vertical resolution were cured. Single precision modifications can be translated to a 3D version, which will then be plugged to the double precision model. Experience learnt during preparation of ACRANEB2 single precision version can be reused for other schemes, underlining the fact that cooperation with their developers will be necessary.

There are discrepancies between observed and simulated brightness temperatures in the 10.8 micron channel. ALARO simulated values for convective cloud tops using the RTTOV scheme were up to 5K warmer than the values measured by SEVIRI. That would mean convective towers in ALARO may not reach sufficient height. Inspection of the CZ tornado case with extra diagnostics from satellite and aerological departments indicates that ALARO cloud top height is acceptable, and the warm bias is likely to come from missing model versus sensor bias.

The implementation of the prognostic graupel is finished. However, there are plans for further validation and possibly tuning. Use of prognostic graupel opens a possibility to diagnose lightning intensity in the model, following McCaul et al. (2009). The subroutine DIAGFLASH is now interfaced with ALARO-1 graupel. Work on calibration of model lightning intensity against LINET measurements is ongoing, using hourly data covering the Czech Republic and its surroundings. (Part of PH5)

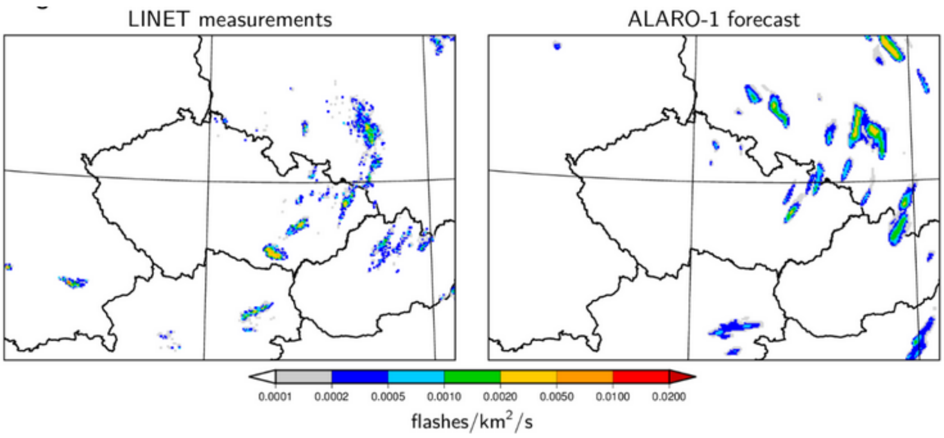


Figure 3.4.3. Average lightning intensity on 26-Jun-2020 between 16 and 17 UTC from LINET measurements (left), and from ALARO-1 forecast starting at 12 UTC (right). Method based on graupel flux across -15°C level is shown, using preliminary calibration.

➢ HARMONIE-AROME

The work on Harmonie-Arome parametrizations has been focussing on the following topics:

- Studies dedicated to improving the model behaviour for low clouds and fog. The effects of reducing the cloud droplet number concentration CDNC in the ICE3 scheme and of assuming a vertical profile for CDNC in the lowest km of the atmosphere, have been investigated extensively and shown to have positive impact for most domains. These changes have therefore been included in Cy43h2.2. An increase from 65 to 90 vertical levels also resulted in a better representation for fog. The model behaviour for low clouds was shown to be quite sensitive for the gamma distribution assumed in the sedimentation.
- Achieving a consistent description of aerosol - radiation - cloud - microphysics

interactions, and introducing and assessing the use of near-real-time aerosol data from CAMS (see also PH6). The option to use near-real-time data (NRT) for 11 aerosol species from CAMS in the Harmonie-Arome radiation and cloud microphysics schemes has been included in a pre-Cy46h1 Harmonie version. Several case studies and one or two longer-term runs over various domains have shown that the use of these NRT data in a consistent manner is generally beneficial for model performance as compared to using aerosol climatology.

- Improving the model ability to represent the transition from shallow to deep convection, with a focus on the representation of open-cell convection and small-scale showers. With a reduction of too strong momentum mixing by the shallow convection scheme, a more realistic organization of open cell cloud structures could be observed. In the case that additionally also the new ECUME-6 sea surface scheme is used (which produces more realistic surface fluxes over sea), the model cloud cover and precipitation behavior in coastal areas also becomes more realistic for many domains.
- Process studies concerning the atmosphere-surface interaction under (cold, nocturnal) stable boundary layer conditions. At Met Norway, the atmospheric response of Arome-Arctic to the new ISBA-DIF diffusion soil scheme was studied for the nocturnal stable boundary layer. Tendency studies showed that in ISBA-DIF, as compared to ISBA-Force-Restore, the radiation scheme becomes the dominant driver of the nocturnal cooling while the contribution of turbulence diminishes.

Jenny Engdahl finished her thesis on improving the prediction of icing on physical structures in winter through changes in the ICE3 microphysics. These changes, inspired by the Thompson microphysics scheme, resulted in a more realistic description of supercooled liquid water, and through this, in better icing risk and ice load forecasts.

- ***perspectives and priorities on transversal topics for 2022***

  On the transversal topics in Physics, the goals may be formulated as follows:
  - In PH4, it is expected to organize a more continued maintenance of the updated common MUSC version (expected to be defined in 2021), increase the number of ideal test cases and start performing an evaluation of 1D runs for physics packages across the model configurations (CSCs, Arpege) with the common MUSC cycle based on cy46t1 created during the working week in November 2021. Work has continued to increase the portability and ease-of-use of MUSC, in the form of a containerized version (https://github.com/Hirlam/HarmonieContainers), and a MUSC virtualbox created for teaching purposes.
  - We will finalize the drafting of a coordinated work plan for the development of model outputs within the ACCORD common codes (PH5).
  - For PH6 (cloud-aerosol-radiation interaction), significant technical and design work is expected, in order to clean the overall CAMS data workflow and design the NWP code internal data flow and interfaces. Given the planned re-factoring of the physics interface codes (PH9, SPTR1), a close liaison and an interaction between these groups is expected.
  - For PH9, the re-factoring analysis of the physics interface codes should be completed; the roadmap proposal for enhancing the interoperability across the physics packages should be drafted and proposed to STAC and Assembly (this is the WG's main deliverable). Exchange and information with the physics teams will continue.
  - work in PH7 and PH10 will continue as research topics. For PH7 (3D effects), some increased collaboration across ACCORD teams could be triggered by the outcomes of the WG about very high resolution modelling (see below §**3.9**).

3.5. Surface analysis and modelling (SU1 to SU6)

- ***overview of the activity in the area***

The ACCORD strategy for 2021-2025 divides the surface activities in three main topics:

surface model, physiography and data assimilation. The 2021 activities in these topics include:

Surface model:
The main ACCORD NWP surface model is SURFEX, although all NMSs have not yet activated SURFEX in their operational setups. Work on activating SURFEX for the ALARO CSC is ongoing. SURFEX offers a large number of options where the operational ones for the ISBA (natural land) tile, currently shared by all NMSs, are ForceRestore soil and D95 snow. This has been the situation for many years but now we see very concrete steps towards more advanced surface model options including diffusion soil scheme (DIF), explicit snow scheme (ExplSnow), multi-energy balance (MEB) and prognostic Leaf Area Index (A-gs). For the urban tile the town-energy balance (TEB) model is applied by many but not yet all. Activities are ongoing to evaluate more advanced TEB options which handle vegetation within the urban tile (LGARDEN) and anthropogenic heat sources (the building-energy model BEM). The lake tile is handled operationally by the lake model FLake in a few NWP setups while in most setups the lake tile is still handled more simply. Work on activating FLake is ongoing. For the sea tile the sea-surface temperature (SST) is prescribed from boundary conditions by all NWP setups while for sea ice some have activated the ice models SICE or Gelato. Different options for energy fluxes are also applied and evaluated. Quite some efforts are invested in development and evaluation of wave models (mainly WW3) and its coupling to SURFEX via the coupler OASIS.

Physiography:
SURFEX requires a number of physiography databases as input depending on activated options. The minimum number includes topography and land cover. The land cover databases for SURFEX are named ECOCLIMAP, first and second generations. Most NMSs evaluate and apply the first generation while a few have invested in the second generation. Any step towards a new ECOCLIMAP version requires considerable investments in model tuning to keep good, or achieve better, scores for the main near-surface NWP outputs. Some research is ongoing to look at alternatives to ECOCLIMAP. These activities are triggered by different needs such as insufficient details in ECOCLIMAP or need for more high-resolution land cover.

Data assimilation:
The combination of CANARI for surface analysis of SYNOP observations and Optimal Interpolation (OI) for soil data assimilation (DA) have been around for many years and are still totally dominating the current operational NWP setups. However, a lot of development and research are ongoing with focus on new algorithms such as Extended Kalman Filter (EKF), Ensemble Kalman Filter (EnKF) and Ensemble and OI combination. On the observation side activities are ongoing to include satellite products of soil moisture, snow extent, Leaf-Area Index (LAI) and satellite radiances relevant for soil and ice surface temperatures. The access to crowdsource data (e.g. Netatmo and WOW) have triggered development of alternative tools for surface analysis including titanlib for quality control and gridpp for analysis.

- ***organisation of the work within the consortium***

The surface work package leaders are, according to the ACCORD MoU, responsible for leading the execution of the work, monitor the progress and alert the MG of any difficulty encountered. Together with the ACCORD surface Area Leader Patrick Samulesson, the leaders are Benedikt Strajnar (LACE data assimilation area leader), Bogdan Bochenek (LACE physics area leader), Ekaterina Kourzeneva (HIRLAM surface project leader), Camille Birman (surface data assimilation at Météo-France), Adrien Napoly (surface physics at Météo-France), Sylvie Malardel (ocean activities at Météo-France), Patrick Le Moigne (SURFEX team manager), Rafiq Hamdi, Stefan Schneider and Samuel Viana.

Until now three surface Thematic groups have been established to organise more specific research and development. These are “Snow Analysis” led by Ekaterina Kurzeneva, “Urban group” led by Rafiq Hamdi and “Multi-layer surface physics group” led by Patrick Samuelsson. A joint data assimilation and surface team on “Coupled Atmosphere-Surface DA” is led by Roel Stappers and Ekaterina Kourzeneva. Also, the surface area has monthly meetings, third Tuesday in every month, intended for presentations and discussions about progress and problems.

At least once per semester surface working weeks are arranged. The focus of these weeks will vary between conference style, training and work together.

The surface WPs on data assimilation and observations (SU1-2), physics (SU3-4) and physiography (SU5) represent both near and long term NWP activities while SU6 "Coupling with sea surface/ocean" represents more long term activities looking at the implementation time scale.

- ***highlights from 2021***

Evaluation of multi-layer surface physics in AROME setups
Active testing and evaluation of the more advanced surface model options DIF, ExplSnow and MEB in 3D AROME setups have shown good progress in the last year. The HARMONIE-AROME CSC has been running successfully by MetNorway over their AROME-Arctic domain with this configuration, including SEKF surface assimilation, for more than two years and will soon go pre-operational. The setup has been improved over the last year. Similar HARMONIE-AROME setups are under testing also for other domains. These are actually the first 3D setups ever where the MEB scheme is used. Until now the MEB scheme has solely been evaluated in offline SURFEX setups. Tests with DIF have also been evaluated for the AROME-France CSC and have shown that soil heat flux may need further improvements.

Roughness sublayer - new development for SURFEX
The Harman and Finnigan (2007) formulation of the roughness sublayer (RSL) over tall vegetation has been implemented, developed and evaluated in SURFEX over the last year. The motivation for this work is that the classical Monin–Obukhov Similarity Theory, currently applied in SURFEX over land, does not resemble observed energy exchanges and roughness lengths over tall vegetation well enough. Results look promising but more evaluation is on its way. The figure 3.5.1. shows how RSL roughness (m) over forest now varies in space (for a specific time) as a function of e.g. local surface stability.

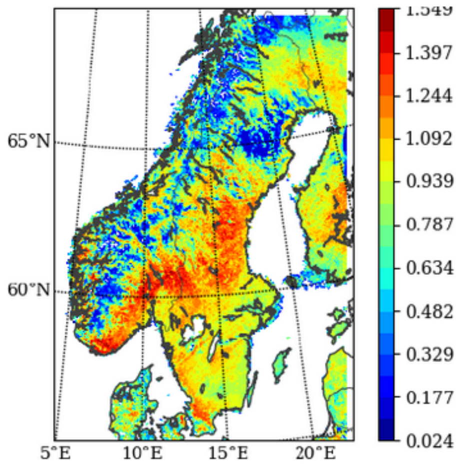


Figure 3.5.1. Map of Roughness Sublayer values (in m)

Achievements in the process of activation of SURFEX for the ALARO CSC
While working on coupling ALARO with SURFEX, investigation of the roughness length treatment in SURFEX revealed several inconsistencies between the original ISBA implementation and SURFEX, as well as some bugs on the SURFEX side. It also turned out that some tunable ISBA parameters, important for NWP, are hard-coded in SURFEX. A set of code fixes correcting these drawbacks was prepared and partially validated. There are still some issues to be addressed; the modset is intended for NWP commit. Modset documentation is in preparation.

While ALARO with SURFEX is not operational, it is desirable to benefit from the new topographic (GMTED2010) and physiographic (ECOCLIMAP) datasets on the ISBA side. Since the e923 configuration was not interfaced with these new datasets (except for the mean orography and land-sea mask), a procedure for transferring the subgrid-scale orographic fields (standard deviation, anisotropy, orientation of the main axis) and roughness lengths (subgrid-scale orography and vegetation) from PGD and .sfx files into e923 clim files was made available on MF's HPC "belenos". It can be extended to other parameters (soil and vegetation characteristics, albedo and emissivity). Such a step is highly desirable at high resolution, since the quality of some old e923 datasets is questionable. On the other hand, modified surface and vegetation characteristics alter model results dramatically, so that retuning of ALARO with SURFEX datasets will be necessary.

Physiography steps beyond ECOCLIMAP
Triggered mostly by lack of preciseness and resolution in current ECOCLIMAP land cover databases, we see activities on how to locally or regionally improve the information. At Met Éireann Machine learning (ML) has been successfully combined with physiography databases and satellite information to achieve greater details and more correct description of land cover over Ireland (see in this report,

Section 3.10). In Austria we have seen how national physiography databases can be combined with ECOCLIMAP to achieve great details over Vienna for SURFEX offline simulations. Also, increased experience has been gathered the last year on the use of ECOCLIMAP Second Generation which is the default physiography of HARMONIE-AROME CSC since cy43h2.1.

Development and evaluation of Kalman Filters for surface assimilation
Development of Kalman Filters supports the needs to assimilate both an increased number of control variables by more advanced surface physics and an increased number of satellite observations, products and radiances. In Hungary they are heading for a new operational AROME setup where ForceRestore/D95 schemes are combined with SEKF for the soil assimilation. Final tests will soon be performed. For HARMONIE-AROME and cy46h SEKF is developed to support the new surface physics combination DIF/ExplSnow/MEB. This setup is soon going preoperational for the AROME-Arctic domain. In both these setups it has been proven successful to apply an ACCORD-developed method of testing if linearity is achieved by both negative and positive perturbations for Jacobians in forecast mode. For assimilation of ice surface temperature (L2 NRT VIIRS SIST product from OSISAF) a bias aware EKF method has been developed for the SICE sea-ice model which is operational in HARMONIE-AROME. Validation shows nice improvements in near-surface temperature statistics.

Last year good progress was made in EnKF development in the framework of SODA and HARMONIE-AROME. At the moment SYNOP observations are assimilated but satellite radiances are in the development pipeline.

Implementation and testing of satellite observations for surface data assimilation
The number of satellite observations being implemented and evaluated by ACCORD scientists increases continuously. Surface temperature related satellite observations are now being implemented and evaluated for sea-ice areas connected to the sea-ice model SICE in HARMONIE-AROME and for SEVIRI retrieved land surface temperature in AROME-France. Tóth and Szintai (2021) has published how they assimilate satellite Leaf-Area Index (Spot/Vegetation and PROBA-V) in an offline SURFEX environment forced by ALADIN. Similar research is ongoing in Austria where Sentinel-2-based LAI observations are utilized. Satellite soil-moisture (ASCAT/Metop) has also been assimilated by Tóth and Szintai (2021) and is implemented via microwave backscatter and brightness temperature in the HARMONIE-AROME EnKF setup. For snow assimilation, snow extent is derived from H SAF H32 (Metop/AVHRR) satellite data via a Barrel method and is now being evaluated in the MetCoOp setup of HARMONIE-AROME.

Assimilation of crowdsource observations
An enormous observation potential for surface data assimilation is present in the increasing amount of crowdsource observations. Assimilation of Netamto citizen observations are now implemented in the MetCoOp nowcasting system based on HARMONIE-AROME where titanlib is used for quality control and gridpp for surface analysis.

- ***perspectives and priorities for 2022***

Perspectives with respect to the three main topics surface model, physiography and data assimilation:

Surface model:
Use and evaluation of the more advanced surface land physics including DIF/ExplSnow/MEB and A-gs in ACCORD CSCs will be high up on the agenda. Work on activating FLake as the lake model in more setups is ongoing. For the urban tile activation of TEB in setups where it is still not used should be inspired and more sophisticated TEB settings, first of all the garden option, will be looked into. The ocean and wave modelling community will continue the coupling development and evaluation with respect to the ACCORD NWP system. For more immediate NWP needs alternative SST products will be considered. Activation of SURFEX in the ALARO CSC has high priority.

Physiography:
Evaluation of different ECOCLIMAP versions will continue, especially the second generation version which has until now only been evaluated over a limited number of domains. At the moment we see

different approaches on how to meet needs for more details and preciseness in land cover. Such different approaches will continue for a while so we can gather more experience, and based on that hopefully make a more long term strategy on how to proceed.

Data assimilation:
Applications and development of different surface assimilation approaches, like OI, EKF, EnKF, will continue to run in parallel since they fulfill different short term needs. For example, for EPS based NWP systems EnKF is an alternative while for deterministic based NWP systems EKF is more developed and attractive. The development and evaluation of observations for surface data assimilation based on satellite products and radiances will continue. More work is needed on the mentioned observations with respect to surface temperature, LAI, soil moisture and snow extent. We will also see continued growth in the use of crowdsource observations for NWP and development of the tools needed for this.

3.6. Ensemble forecasting and predictability (E1 to E7)

- ***overview of the activity in the area***

  Two areas of development stand out in 2021: Model perturbations, especially parameter perturbations which account for 22% of the hours spent on EPS in the first six months of 2021, and post-processing which account for more than 40% of the hours spent on EPS.

  There have been substantial efforts to include or further develop parameter perturbations (mostly stochastic; SPP) in AROME-EPS, HarmonEPS and C-LAEF. Parameter perturbations are generally found to improve ensemble spread, either as a supplement or an alternative to stochastically perturbed parameterization tendencies (SPPT).

  The post-processing development is two-fold: One that focuses on providing new products and tools (including new probabilistic products and extreme forecast indices) for our internal users, primarily the meteorologists who prepare daily forecasts and issue warnings of high impact weather; the other focuses on products tailored to external users like the renewable energy sector.

  More specifically, the development in the work packages include
  - E1:
    - Further development of AROME-EPS with new AROME physics and an upgrade to horizontal resolution 1.3 km
    - In addition to SPPT perturbations several versions of parameter perturbations have been investigated. A screening of many uncertain parameters has reduced the number to 8 parameters that have a strong influence on the forecast variation.
  - E2.1-E2.5:
    - Extensive work on development of SPP for HarmonEPS-cy43
    - understanding a bias problem in stochastic perturbation of soil moisture
    - tested whether HarmonEPS is suitable for deriving background error statistics for data assimilation, but found that the current configuration of MetCoop's EPS is not suitable
  - E3-E4:
    - Three LAM-EPS (2 Arome + 1 Alaro) operational within LACE
    - upgrade to cy43t2
    - adaptation to increase in vertical levels in IFS-ENS
    - stochastic surface perturbation scheme
    - extension of C-LAEF SPP scheme
    - post-processing: precipitation phase, new EPSgrams, MSEA domain for coupling ocean models in the Mediterranean to A-LAEF
    - continuous harp verification
  - E6
    - Calibration in high resolution for use in yr.no
    - Comparison between statistical precipitation ensembles based on a 3-year

deterministic re-forecasting dataset and KNMI's EPS

- E7
  - Improved products for meteorologists (especially regarding high-impact weather)
  - products for external users, e.g. wind power production
  - analog calibration method

- ***organisation of the work within the consortium***

  The work packages in 2021 have to a large extent followed the canonical system configurations, i.e. a Meteo-France work package (E1), a HarmonEPS work package (E2), a C-LAEF/AROME-EPS work package (E3) and an A-LAEF work package (E4). In addition, there are two post-processing work packages that are independent of CSC: Calibration (E6) and user-oriented approaches (E7).

  Due to the covid-19 situation it has not been possible to meet physically in 2021. In addition to within-family online working meetings there has been one meeting on ACCORD level where the ambition is to enhance collaboration across families. In the meeting on Ensemble calibration and User-oriented approaches many of the activities in the new E7 work package were presented.

- ***highlights from 2021***

  The Stochastically Perturbed Parameterizations scheme (SPP) is implemented and tested in HarmonEPS. SPP introduces stochastic perturbations to values of chosen closure parameters representing efficiencies or rates of change in parameterized atmospheric (sub)processes. SPP in this first version in HarmonEPS perturbs 11 parameters, active in different atmospheric processes and under various weather conditions. The main motivation was the lack of variability seen in cloud products in HarmonEPS, as reported by duty forecasters. SPP in this first version is able to increase variability in a range of weather variables, including the cloud products. However, for some weather variables the root mean squared error of the ensemble mean is increased and the mean bias is impacted, especially in winter. This indicates that (some) parameter perturbation distributions are not optimal in the current configuration, and a further sensitivity analysis is required. The SPP code is agreed with ECMWF and will be merged with ECMWF in CY49. Figure 3.6.1 shows the scorecard including statistical significance between an experiment with SPP and a reference experiment without, for June 2019.

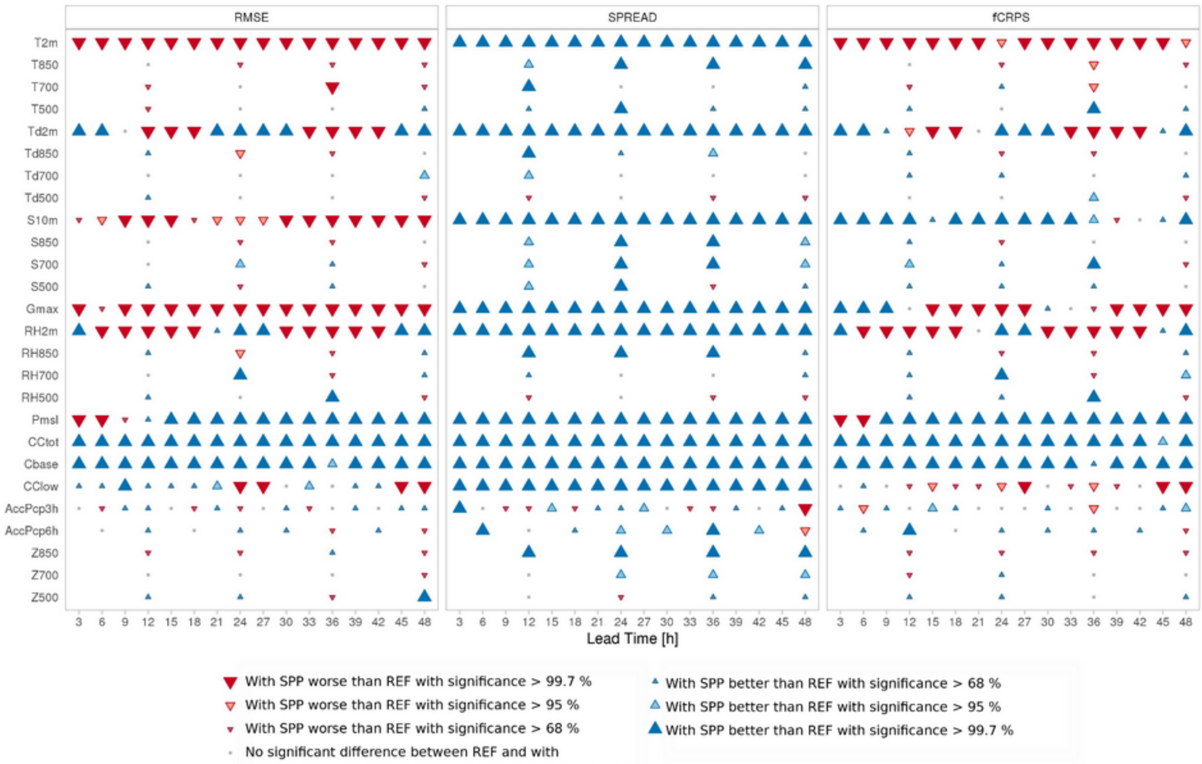


Figure 3.6.1. Scorecard between an experiment with SPP and a reference experiment without,

An alternative parameter perturbation scheme has been implemented in AROME-EPS at Météo-France and evaluated in the PhD work of Meryl Wimmer. Following advice from physics experts, 21 uncertain parameters to perturb have been selected. In a first step, sensitivity analyses lead to a short list of eight parameters with the highest impact on AROME forecasts (Figure 3.6.2 left). Different configurations of fixed parameter perturbations have then been evaluated. Each member uses a different set of parameters values, which are either tuned to optimize the average CRPS score, or randomly drawn from a uniform distribution. Results indicate a large improvement of the AROME-EPS performances with all configurations for most near-surface variables including 10-meter wind speed and precipitation (Figure 3.6.2 right). There is also a significant impact of the optimization procedure. It is finally interesting to see that reducing the perturbation to the 8 most influential parameters provides similar results as perturbing the full set of parameters.

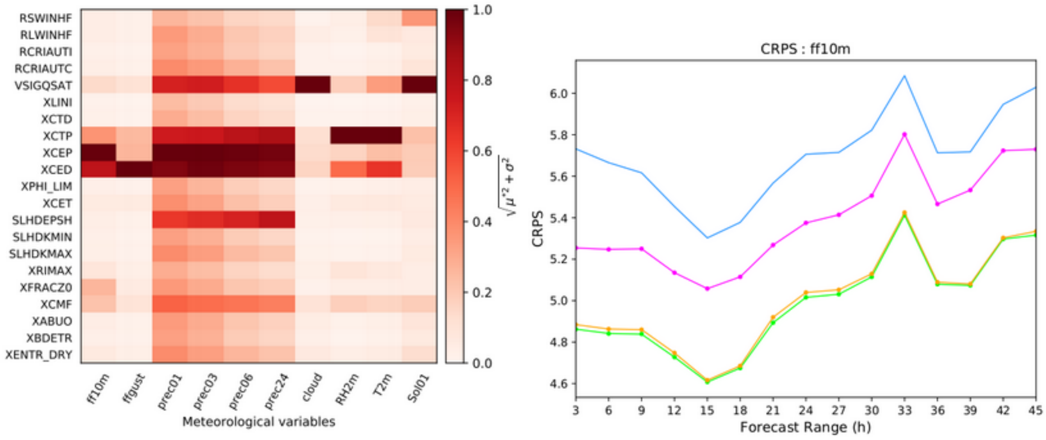


Figure 3.6.2. Left: Influence of the AROME parameters on the prediction of several variables. The closer the value is to 1, the more influential the parameter.
Right: CRPS of 10-meter wind speed computed over a 3-month winter period. Different AROME-EPS configurations are compared : baseline SPPT (blue), random parameters (pink), optimized perturbed parameters (21 parameters in green, 8 most influential parameters in orange).

One of the main motivations for running EPS is to improve prediction of high-impact weather. C-LAEF provided a nice example when a severe hailstorm near the Austrian/Czech border was accurately predicted on 24 June 2021. Approximately 250 persons were injured in the hailstorm and an associated tornado. Figure 3.6.3 shows good agreement between the C-LAEF probability of hail and the verifying hail analysis.

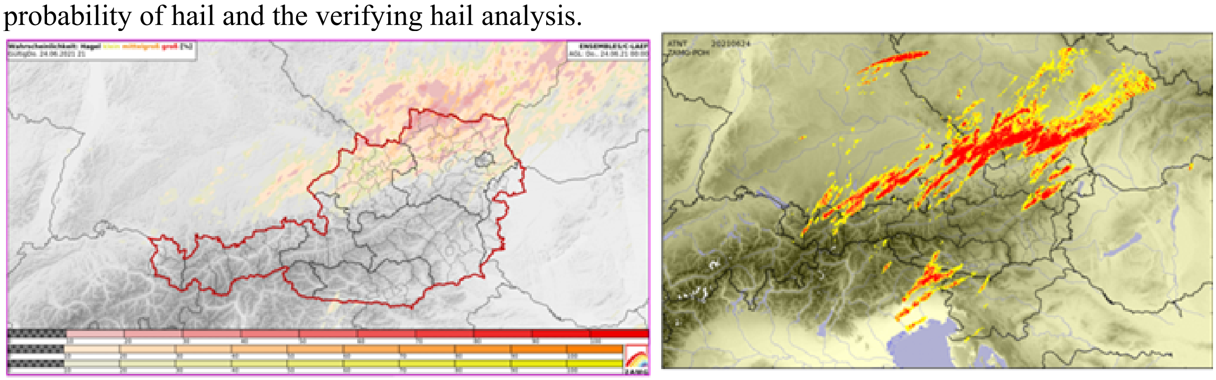


Figure 3.6.3. C-LAEF probability of hail (left) and hail analysis (right) for 24/06 21 UTC.

- ***perspectives and priorities for 2022***

The rolling work plan for 2022 has been reorganised for EPS, so that the work packages are organised independently of CSCs in order to emphasize the ambition to increase interoperability. The post-processing work packages E6-E7 have been kept, while E1-E4 have been replaced by new work packages, E8 EPS preparation, evolution and migration, E9 Model perturbations, E10 Initial condition perturbations, E11 Surface perturbations and E12 Lateral boundary conditions.

With the expectation that the travelling situation will normalize in 2022 at least one physical working week will take place in 2022 (Innsbruck in spring). As development is ongoing in both parameter and surface perturbations in all families, it is a priority to identify common research tasks within these two areas. Similarly for post-processing, in coordination with the post-processing activities in SRNWP-EPS.

3.7. Meteorological quality assurance and verification (MQA1 to MQA3)

- ***overview of the activity in the area***

The work in this area entails the following three activities:

1. The development of the harp verification system (WP MQA1)
2. The development of new metrics and methods for verification and quality control (WP MQA2)
3. Quality assessment of new cycles and alleviation of model weaknesses (WP MQA3)

The present overview is based on summary reports from CSCs and entries in the common manpower register, supplemented by published research articles and presentations at meetings and thematic seminars, as well as direct interaction with many responsible scientists. A consortium-wide questionnaire about practices of meteorological quality assurance, launched by the management team early in the Summer, is still open at the time of writing. Nevertheless, the answers already received have provided much information about the gathering and usage of operational verification data at local teams reported under heading MQA3.

In the whole area, 100 months of work were registered by the local teams during the first two quarters, with 76% allocated to MQA3, 16% into MQA2, and 8% into MQA1.

MQA1 The efficiency and versatility of the harp verification software was enhanced by improved code design, by developing the readers for GRIB, FA, and HDF5-files for spatial verification, and by implementing an interface to the OPLACE observational database. New bootstrapping functions allow improved estimates of the significance of differences in scores, and especially serve to improve the value of score cards. By way of user support, a tutorial document was made available on https://harphub.github.io/harp_tutorial/index.html. In addition, a harp working area was set up on slack (https://harp-network.slack.com) and has proven to be an efficient means to exchange experiences between developers and users, and to get peer-support related to specific problems. The use of harp within the consortium is spreading, often involving interfacing with local data sets and software.

MQA2 Two new metrics targeting the evaluation of high resolution forecasts and extreme events have been presented and have been applied in evaluating forecasts of precipitation: the neighbourhood-sensitive continuous rank probability score (Stein and Stoop, 2021 submitted to Monthly Weather Review) and the SLX-metric for verifying the spatial structure of extremes (Sass, B. H., 2021, *Meteorological Applications*, 28(4), e2015. https://doi.org/10.1002/met.2015)

Several new data sources have been tried in various local teams. *Cloud mask* data from the EUMETSAT SAF-NWC was used to evaluate different configurations of the HARMONEPS ensemble predictions system by means of the fractions skill score (FSS) (Frogner et al. 2021, submitted to Monthly Weather Review). A tool using *merged radar and rain gauge* data for spatial precipitation verification using FSS was implemented and used to evaluate the impact of assimilated radar observations in the Czech republic. *Machine learning* methods were tested for evaluation of AROME-BG microphysics options using *lightning detection data*. Observations from *solar power plants and wind farms* were used in Hungary to verify

AROME-forecasts of *global radiation* and w*ind speed at hub-height* (100 m). In Austria *INCA high-resolution analyses* are used for verification of single precipitation forecasts in a multi image utility, that presents a number of scores together with visualized precipitation fields from many sources, allowing users to examine scores and fields in a single glance. The utility is used to help forecasters evaluate forecasts in real time. The use of *scorecards* in research and in evaluation of e-suites is spreading in the consortium, and developments have taken place in terms of metrics displayed (France) and in terms of reliability (harp).

MQA3 spans a wide range of activities including maintenance of routine verification of operational forecasts and gathering of feedback from forecasters, evaluation of new cycles through verification and forecast diagnostics over extended periods or in case studies, as well as identification of weaknesses in modelling and data assimilation and search for improvements.

Verification of operational forecasts and evaluation of local implementations is the responsibility of local teams, and practices may vary from team to team. Generally, observations from reporting weather stations and radio soundings are main sources of data, but radar based precipitation retrievals, high-resolution analyses, wind data from wind farms or scatterometers, lightning detection data, or crowd-sourced observations are sometimes used as well. Mainly point-wise metrics are used in routine verification, but spatial methods are applied to precipitation forecasts by some teams. Many institutes use locally developed software for generating and presenting material, or else the Monitor-tool developed in the HIRLAM projects. However, the use of harp is increasing. Access to results, in the form of data or graphics, is typically restricted to the institutes where they are produced, or among institutes sharing a common production system. In the case of RC-LACE, however, graphics are shared among the partners through a password-protected portal, the same is true for some material from the so-called RCR-centres of HIRLAM-C, having committed to applying operationally the HARMONIE-AROME reference system. The material in these two portals is generated by Monitor. Typically, the results of operational verification are reported in periodic or ad hoc summaries, and presented at local gatherings of users and developers, but access to the material is often restricted to the producing institute. The work plan calls for gathering coordinated user input, and a meeting between users and developers of the HARMONIE-AROME CSC was planned to be held but had to be postponed owing to travelling restrictions related to the COVID-19 pandemic.

Verification and diagnostics in aid of model development and for evaluation of new local implementations and e-suites takes up the bulk of the reported work under MQA3, typically involving running and analysing lengthy parallel experiments and detailed case studies. As in the case of routine monitoring, local teams often work quite independently of each other. An exception is provided by the members of the HIRLAM-C project, who join forces to maintain and develop a complete common reference version of the HARMONIE-AROME CSC, ready for installation and operational application by the members, and undertake coordinated evaluation of new releases.

In-depth analysis of individual cases is an efficient methodology for evaluation of forecasts and forecasting systems, and forms an important part of meteorological quality assurance. In order to help and coordinate the undertaking of worthwhile case studies, a common register of cases suited for reforecasting and detailed scrutiny is maintained by RC-LACE. Often the cases selected for detailed analysis are accompanied by severe or significant weather in one form or another. Such is the case, e.g., in the Austrian hail event of 24th of june 2021 or flood event on the 17th of july 2021, both described in the Austrian national poster at the 43rd EWGLAM and 28th SRNWP meeting in September 2021 (Weidle et al., https://drive.google.com/drive/folders/1GPYxJIAbkk0ibcU9_rSlEJs2YQBuAduc), or in the analysis of a derecho event in Poland in 2017, described by Bochenec et al. in the first ACCORD newsletter (pp. 40-42), or in Meier et al (pp. 119-126) on forecasting screen-level temperature minima in alpine regions. The scientific challenges and model deficiencies related to forecasting the visibility and the occurrence of fog have recently received much attention throughout the consortium, and several studies have been carried out related to fog.

Four such studies are reported in the first ACCORD newsletter: Antoine et al (pp. 107-111), Bari et al. (pp. 96-106), Chikhi et al (pp 112-118), Clancy et al (pp. 82-95). A webinar devoted to modelling clouds and fog was arranged on the 22nd of March 2921 by HIRLAM-C in the frame of MQA3. recordings and material are available at: https://hirlam.org/trac/wiki/Meetings/Physics/Fog20210422.

- ***organisation of the work within the consortium***

  Local teams are the principal unit for monitoring and evaluating operational installations and e-suites, as for the direct interaction between users and developers of the forecasting systems. Concerted trials of new cycles, and sharing of data and user-experiences among the partners, is at least partly organized at the level of Canonical System Configurations. A meeting of the MQA-team, looking into progress and plans within the area, and a webinar on modelling visibility and fog were both arranged as video conferences. A slack working-area for harp has greatly facilitated exchange and peer support among users and developers of harp. A gathering of forecasters and model developers was planned for late 2021, but had to be postponed owing to travel restrictions.

- ***highlights from 2021***

  One ACCORD member, Algeria, has implemented a new routine verification environment, meeting WMO standards for verification of operational forecasts. The upgrade was accomplished with support from the European Union and two other partners in ACCORD (MF and FMI). Details and first results obtained are described in Chikhi et al. (ACCORD NL 1, pp. 25-35).

  OPLACE is the common observation preprocessing system within RC-LACE, built up to collect and deliver meteorological observations in an appropriate format for data assimilation. Until now, data in OPLACE was not immediately available for verification purposes in the common harp environment. In 2021, however, an interface was coded in the library harpIO by Martin Petras from the slovakian team, allowing direct access to observations provided by OPLACE, thereby increasing the utility of both of these common systems. *Observations available in OPLACE and examples of coverage are given in the following table 3.7.1 and figure 3.7.2*, (Trojáková et al., 2019, https://doi.org/10.5194/asr-16-223-2019):

Observations	Type/Satellite sensor	Platform	Input format	Output format
Surface synoptic	SYNOP, SHIP, BUOY		ASCII, BUFR	OBSOUL
Aircraft	AMDAR, ACARS		BUFR	OBSOUL
Upper-air sounding	TEMP, TEMP MOBIL		ASCII, BUFR	OBSOUL
Wind profiler	E-PROFILE		BUFR	BUFR
Atmospheric motion vectors	GEOWIND, HRWIND	Meteosat 10/11	BUFR	BUFR
Satellite radiances	SEVIRI	Meteosat 10/11	HRIT	GRIB
	AMSU-A/B, MHS	NOAA 18/19	BUFR	BUFR
	HIRS, IASI	METOP-A/B		
	ATMS	SNPP		
Ocean/sea winds	ASCAT	Metop-A/B	BUFR	BUFR

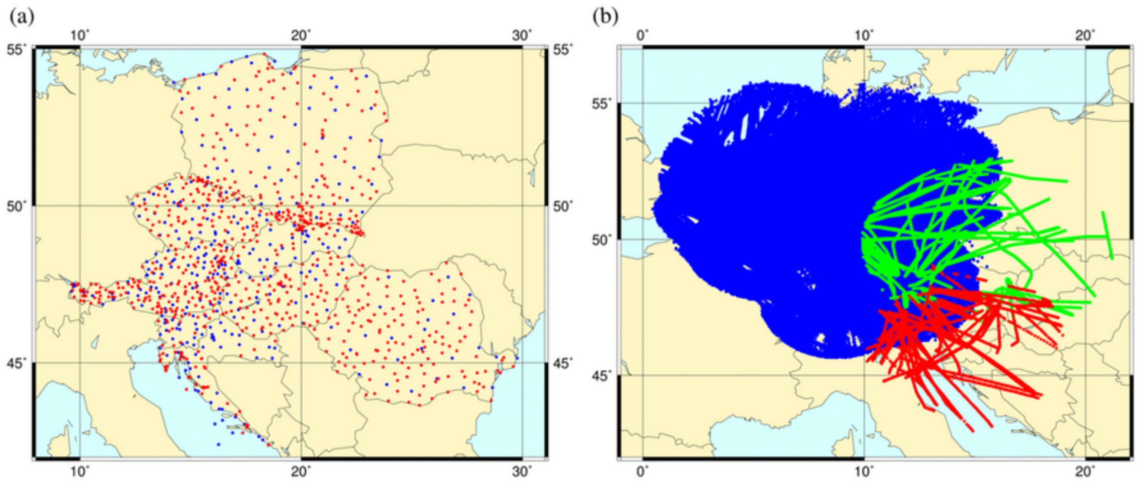


Figure 3.7.2. The geographical distribution of (a) surface observations available in the GTS (blue) and of denser national observations (red) and (b) high-resolution aircraft Mode-S EHS data from KNMI (blue) and Mode-S MRAR data from Slovenia (red) and Czech Republic (green)

The OPLACE capability still exists in a branch of it's own on github and must be installed explicitly from inside other branches:

```
remotes::install_github("meteorolog90/harpIO”)
```

with the correct version of harpIO thus in place, observations can be accessed by calling the function "read_obs_convert" providing the right arguments, e.g.:

```
read_obs_convert(
start_date = 2021061300,
#set start date
end_date = 2021061307,
#set end date
by
= "1h",
obs_format = "obsoul",
#set obs format, options : obsoul, vobs
obs_path = "/users/ext005/app/oplace/# set path to obsoul location
obsfile_template = "obsoul_1_xxxxxy_hu_{YYYY}{MM}# set template
sqlite_path = "/users/ext005/app/oplace/ # set place for SQLite database
country = "hu",
# set country, need to add this arg. because different SID stations names
return_data = TRUE
)
```

- ***perspectives and priorities for 2022***

Constructing a standard package for easy generation and presentation of a predetermined set of deterministic and probabilistic scores, requiring a minimum of intervention by the user, should be a high-priority action in 2022. In support of harp users, a training course on the use of harp will be arranged in February 2022.

The demand for data and methods supporting quality assurance of very high resolution forecasts and models will continue to grow on 2022, driven by needs of ACCORD members and by specific major endeavours like DestinE. Currently under-used observations supporting spatial verification, such as radars, satellite imagery, lightning detection, or crowd sourced observations are taken on board common systems, exploiting, when possible, synergies with observation usage in data assimilation.

Regular verification and diagnosis of operational implementations and e-suites will continue as major activities in 2022. Findings, in combination with feedback from users, and findings from case studies and field experiments inside and outside of ACCORD will provide valuable guidance for further development of common codes.

3.8. Technical code and system development (SY1 to SY4)

- ***overview of the activity in the area***

This area reflects the efforts divided in four work packages covering the Code Optimization efforts (SY1), the Maintenance and development of the Harmonie Reference System (SY2), the Revision of the Harmonie scripting systems (SY3), and the activities Towards a more common working environment (SY4).

The Code Optimization activities (**SY1**) have the main objective to identify and overcome bottlenecks for code computational performance. To discover these blocking points in the code performance, and in its scalability, code profiling and benchmarking techniques have been used.

The coupling part of Arome has been re-written in order to enhance the open-mp parallelization and the computational performance (vectorization and memory cache re-use), by the introduction of the cache-blocking mechanism NPROMA on the coupling data and an on-the-fly analysis of the coupling data contiguity.
The code of the microphysics ICE3 has been deeply re-arranged in order to increase the computational performance, introducing an efficient and tunable microphysic-specific internal cache-blocking mechanism. Lessons have been learned on how to code optimally conditional loops, depending on the nature of the conditions.
Overall optimizations have been measured by 3% to 6% and as it is shown in Figure 3.8.1 for the cycle 48t1.

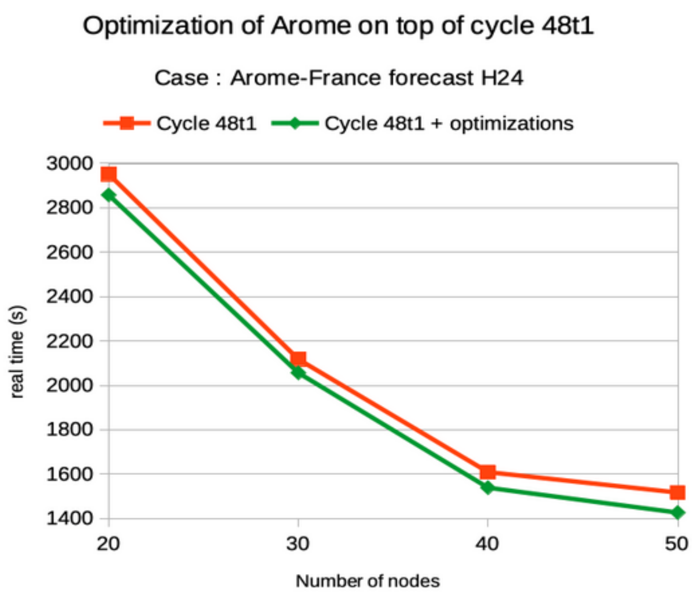


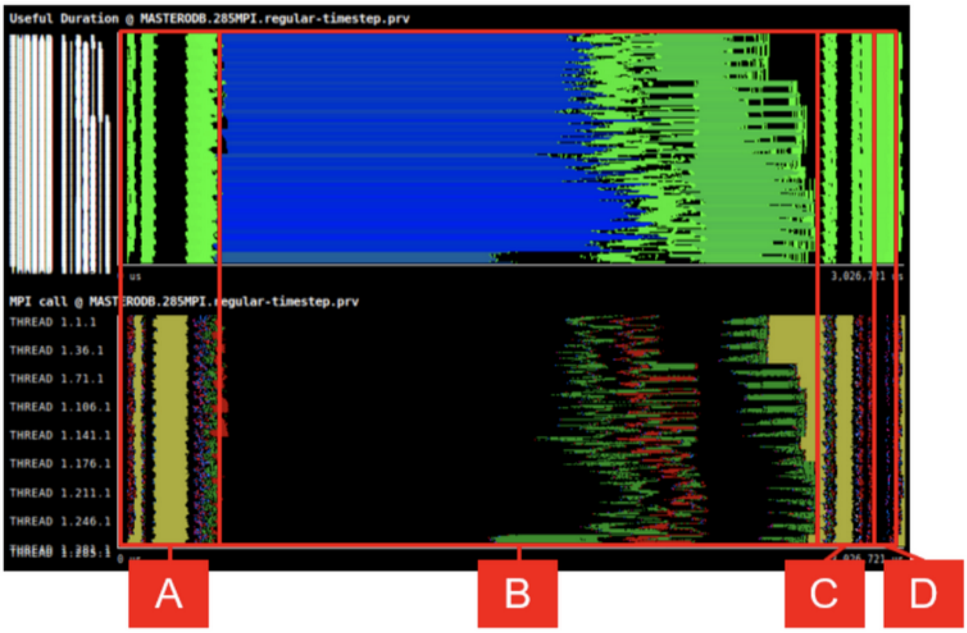
Figure 3.8.1 CY48T1 and CY48T1 optimized code scalability (courtesy by R. El Khatib)

Furthermore, one of the most promising alternatives for reducing the computational cost of models, by up to 40%, is the use of single precision (SP) calculations on certain parts of the model chain. To ensure that the SP implementation is able to reproduce the same forecast quality as in double precision, several tests over different areas have been carried out.

The Harmonie-Arome CSC now has the capability to be compiled and executed in single precision, double precision and dual precision (ie 2 binaries, one in single precision and the other in double precision, are prepared, enabling to build a mixed precision simulation suite). The AROME CSC is being evaluated in SP for the Overseas models in MF. Also, the use of SP computations is currently being explored for the operational EPS suites of some ACCORD partners.

The implementation of new, more expensive algorithms in modeling systems created the need to profile, analyze, and optimize them for operational use. This is the case with the 4DVar data assimilation technique, which Harmonie-Arome will implement in the harmonie-43h2.2 version at the end of 2021 and was also integrated in the CY48T1 version.

To increase the level of competence on activities related with code performance and scalability, HIRLAM funded a project with the Barcelona Supercomputing Center (BSC). During the year 2021, the report of second and final deliverable [(1)] of this project has been published. The study conducted some scalability tests, evaluated code deployment efficiency, established a proper placement for MPI processes, made a profile and trace analysis, made code performance simulation under machine changes and some validation tests after code optimization. The whole project has been based on open source BSC tools. BSC will provide a way to use these tools with few manual interventions and will also provide training to ACCORD system experts in the use of these tools to improve benchmarking and optimization procedures.



A - Inverse transformations
B - Grid-point computations
C - Direct transformations
D - Spectral computations

Figure 3.8.2 Visualization of Harmonie computations per time step using PARAVER BSC open-source tool.

Another important activity related to the usability of the code is the use of software containers to facilitate the deployment of the NWP code in different computational architectures. Some efforts have been made in containerized versions to run on HPC cloud computing infrastructures, such as Amazon Web Services [(2)]. In addition, the MUSC single column model has been containerized and some initiatives have been implemented about running on ARM chipset-based machines.

The maintenance and development of the Harmonie Reference System (SY2) required a substantial effort from the HIRLAM System Group. During 2021, two releases of the Harmonie-Arome model are planned. A technical version, harmonie-43h2.1.1, was declared on February 4, 2021, and final validation tests for the scientific version of harmonie-43h2.2, which includes 4DVar and other important developments, are underway to release this version at the end of the current year. For the first time, EPS testing has been included in the meteorological validation procedure.

In parallel, the harmonie-46h1.beta.1 version was released in June 2021. This version is regularly merged with the Harmonie cy43h2 codes to maintain the same level of development of cy43 in scripts and cy46 codes.

The local implementation of the latest version of Harmonie has shown some difficulties due to the handling of local observations. The use of the SAPP and the WMO Bufr standard could be a better methodology for handling observations. In addition, a new form of the MARS boundary conditions retrieval strategy has been implemented, allowing the acceleration of this procedure in the experiments located at ECMWF.

The default standard for encoding the outputs of the model from the harmonie-46h version will be GRIB2, although GRIB1 or netCDF will continue to be used for SURFEX outputs.

During 2021, the HIRLAM community began prototyping the use of GitHub as a source code management (SCM) tool for all public and private code. Some experience has been gained in this cloud-based SCM, allowing the establishment of new working practices that clearly improve the quality and management of software developments. Some training, in webinar format, on GitHub and the new associated workflows, will take place in late 2021. Other training activities, such as the general Harmonie system training, have been postponed due to the pandemic situation.

The Harmonie Scripting System Review (**SY3**) has some stand-by tasks pending from the decision made at ACCORD on the common SCM solution and how the multi-repository strategy will be implemented. Despite this, a cleanup of the Harmonie scripts has been done, especially in the context of the OOPS implementation in cy46.

Also, for compiling OOPS code and as an alternative optional compilation strategy, cmake has been tested and will be part of the harmonie-46h1 releases. Using this more standardized tool for code building, with broad community support, allows us to reduce circular code dependencias, faster and parallel compilation, and better handling of code interfaces.

One of ACCORD's goals is to increase collaboration within partners. Some of the conceptual measures taken in this regard have been reflected in the COM2.2 work package (Code generation and maintenance: evolution of work practices and environment) and some more practical and prototyping activities were reflected in the SY4 work packages: Towards a more common work environment. The final decision on the organization and management of the code has not yet been made (see the next point Organization of work within the consortium for more details).

The activity that has some independence with respect to the common decisions that will be made about the organization of the code, is the development of unit tests based on DAVAÏ. For reminder, the DAVAÏ testing system enables to test any code version (new development or merge result, for instance). The steps encompass: fetching the codes to be tested, building executables, running sets of integrated or elementary test-cases (representative of canonical configurations including IFS, ARPEGE, AROME, ALARO, HARMONIE-AROME), automatic comparison of outputs to reference outputs, user-friendly display of these results. It is a crucial step in the process of integration and validation of code changes. Now an interface that allows users to run the DAVAÏ tool, independently of Olive scripting, is available on Meteo France platforms and will soon be available on other platforms such as ECMWF. This will allow us to implement tests for different CSCs and a more complete set of tests to ensure the quality of the code that is developed.

[(1)] *HARMONIE PERFORMANCE ANALYSIS: DELIVERABLE 2, BSC-CES-2021-001HARMONIE, scalability, profiling, computational performance X. Yepes-Arbós, M. C. Acosta, Earth Sciences Department Barcelona Supercomputing Center – Centro Nacional de Supercomputación (BSC -CNS)* https://drive.google.com/file/d/1qQfvuEBXnDUfTI839sNfgUSJVa3hNh0S/view?usp=sharing

[(2)] *Porting Harmonie-arome to a public cloud service - AWS Jacob Poulsen, Xiaohua Yang, Eoin Whelan, 1st ACCORD newsletter, Oct 2021* http://www.umr-cnrm.fr/accord/IMG/pdf/accord-nl1.pdf

- ***organisation of the work within the consortium***

As a preliminary step, the ACCORD Management Group decided to have a group of local focal points for activities related to the System. These Local Team System Representatives (LTSR) have been contacted to establish the starting point of the different partners in certain aspects related to the system. To know the level of local use of SCM, a questionnaire has been issued. The questionnaire also covers other aspects such as code documentation management, communication tools, training needs or ideas to implement some more advanced practices, such as more continuous code integration (CI) or continuous deployment. (CD) using SCM capabilities.

The results of the questionnaire will be communicated before the end of 2021 and will help in the elaboration of the proposal to establish a multiple repository of ACCORD source code together with a web interface that will allow users to monitor and track the code modifications of the collaborators in the preparation of new code versions. Parallel to this initiative, an exploratory working document will be shared with the partners "“*Analysis of and further steps towards an ACCORD-wide “forge*” [(3)]", where some possible alternatives to host repositories (public and private) for the consortium have been explained. The answers to the questionnaire will also make it possible to establish the training and communication needs of the community.

[(3)] *A “**Forge**” is the combination of a central, accessible source code repository i.e. the code and the meta-data of its history, together with a web interface designed to monitor and track code modifications from collaborators in preparation of new code releases. See STAC preparatory document (5.Source_forge.pdf)*

- ***highlights from 2021***

During 2021, there are several achievements that will help us to advance in the elaboration of more precise operational forecasts. Reducing computational costs, through the use of simple precision computations, the implementation of new algorithms, such as 4DVar, the prototyping of a more web-integrated SCM, and a more portable DAVAÏ code testing tool, will lead to a more productive code integration process. This more collaborative environment will aid in the integration of the latest scientific developments and code solutions.

- ***perspectives and priorities for 2022***

The final choice of a solution for the ACCORD forge should be in place in 2022, allowing the move of targeted repositories therein and the implementation of the “bundle” tool that should allow to generate a complete forecast system connecting the different repositories.

For code testing the porting of DAVAÏ to the ECMWF HPC, workstations, and other supercomputers will allow the increase of code testing capabilities by introducing tests that will cover different scopes like CSCs configurations, single precision computations and other compilation contexts like bundling tools and compilation systems.

The establishment of the ACCORD forge was considered a necessary first step to open the possibility of collaborating in other parts of the modeling chain like scripting systems. The minimum requirements and functionalities that a common scripting system must cover, as a result of the analysis of the questionnaire that will be issued before the end of 2021, will be determined. After that, an exploratory and prototyping phase of the current available solutions will be carried out to ensure that all the functionalities previously determined can be covered.

3.9. Towards modelling at (sub-)km resolution (HR1)

- ***overview of the activity in the area***

  Sub-km ACCORD NWP applications are becoming increasingly popular, for several reasons. Firstly, the continuous increase of resolutions of global NWP systems remains a strong driver for the LAM community to keep a leading role in exploring numerical modelling at much higher scales (i.e. beyond the km-scale). This trend is further encouraged by the expected gain of realism in the forecast products, provided that for instance the stationary forcing can be well represented. Improving the surface and physiography fields description is one important aspect here, and a start has been made with exploring to achieve this with a combination of high-resolution satellite maps and machine learning (see section 3.10). Secondly, users do require high resolution forecast products for a number of applications like wind adaptation, local forecasting (like over airports) and urban applications, and extreme events like wind storms. Thirdly, the preparation of an ACCORD-based proposal for the on-demand LAM digital twin in the context of Destination Earth has triggered additional brainstorming and certainly motivation into ultra-high resolution modelling.

  The activity on VHR modelling currently is summarized within the HR1 work package. It encompasses work on model numerics (evaluation of the SISL scheme, evaluation of grid point horizontal diffusion SLHD, stability tests in domains with complex orography for a wide variety of model options), test cases including field experiments and research work on using crowd-sourced observations for model evaluation.

- ***organisation of the work within the consortium and WG on Very High Resolution Modeling (VHR-MOD)***

  The work is for the time being not specifically structured, which partly is due to its transversal nature. Much of the R&D efforts are currently driven by user needs, and this context explains that a variety of hectometric configurations have appeared in the consortium. An effort has therefore been initiated by the ACCORD MG in order to foster teams and scientists who are motivated by VHR modelling applications and research, and a dedicated WG has been formed. The goals of the WG are to identify a few specific VHR model configuration designs that should be promoted to trigger research on specific use cases (user driven, complex orography etc.), elaborate on available observations for validation, elaborate on predictability at these very high scales.

  The WG started in September 2021 with an overview of existing material, existing configurations across ACCORD and a survey of user needs. It is expected that the WG will continue until spring 2022, possibly addressing suggestions for some shared and coordinated work on case studies and recommendations for longer term research priorities. The outcome of the WG will be discussed at MG level (several MG members participate in the WG).

- ***highlights from 2021***

  Rather specific experiments were performed in SHMU using ALARO on 325m horizontal resolution in high wind conditions in order to downscale the wind field dynamically to the mountainous terrain in high resolution. The specific domain is on 1600x960 grid points run with linear grid and NH dynamics with 12s time step and DFI initialization run with 20s time step. The study highlighted the need to improve the physiography data for these hectometric resolutions (topography and other surface characteristics).

An AROME-500m version has been designed for studying the modelling of fog occurrence and the life cycle of those events, in the framework of the SOFOG3D field campaign. The AROME design includes the definition of a specific set of 156 vertical levels, with a first model level at 1m height. The hectometric model version is compared with a 1.25km version, which uses settings close to the operational AROME-France configuration. Two microphysics schemes are also evaluated (ICE3, LIMA). This work is part of the PhD thesis of S. Antoine in MF. Experimental results suggest that the hectometric (hm) configuration performs statistically better than the km-scale version over the 4 month period of SOFOG3D. The hm-scale version provides a much higher hit rate, at the expense of a higher false alarm rate though. On the whole, a synthetic index like the Critical Success Index rates higher for the hm-scale version, despite a higher frequency bias of fog forecasting (see Table 3.9.1 below, from S. Antoine et al. in ACCORD Newsletter 1).

	Critical Success Index[2]	Hit Rate (HR)	False Alarm Rate (FAR)	Frequency Bias Index[3]
1.25km L90	0.41	56%	38%	0.91
500m L156	**0.44**	**67%**	**44%**	**1.2**

Table 3.9.1. Impact of the AROME grid on fog forecast for SOFOG3D cases. Comparison is between 1250m L90 and 500m L156 using the ICE3 microphysics scheme, with subgrid condensation and without deposition. Forecasts are from 00 UTC run for lead times +25h to +30h. The differences between the values of both rows are all statistically significant (Bootstrap test with 95% confidence level).

In the continuation of this work, the life cycles of fog events are now being evaluated for different IOPs, comparing the two microphysics schemes and different settings therein (subgrid condensation, deposition).

- ***perspectives and priorities for 2022***

  The deliverables from the VHR modelling WG should be available for spring 2022. The expectation is that this material will help foster more exchange of scientific results across ACCORD, and possibly build the one or other coordinated VHR study. The scientific priorities will remain user-driven, and focus on the evaluation of hectometric model configurations over flat terrain (often associated with forecasting for aviation purposes) or complex orography (where a clear link with research on 3D turbulence exists). At the level of meteorological phenomena, VHR activity for wind adaptation, for fog and visibility and, in the far-reaching resolution of 100m-200m, for urban effects, will be continuing. The potential implication of a number of ACCORD teams in Destination Earth activities would provide an additional push at the level of application design and post-processing. Potential benefits at the level of long-term research could be desirable, however this will likely depend on the overall definition of deliverables in view of an on-demand LAM digital twin.

3.10. Machine Learning (ML1)

- ***overview of the activity and WG on the use of ML for NWP problems***

  The use of ML approaches within ACCORD teams rather is expanding when one considers

2 *CSI=Hits/(Hits+False Alarms+No Detection)*

3 *FBI=(Hits+False Alarms)/(Hits+No Detection)*

post-processing applications (ie what is downstream of the NWP model application, but would use its outputs) or EPS (in link with reduction of information, calibration or ensemble design). Examples of applying ML techniques in core parts of the NWP system are comparatively sparse. Efforts at DMI on computing gas optical properties for a radiation scheme are materializing, in collaboration with ECMWF (Ukkonen etal, in JAMES, 2020[4]). The use of ML algorithms for the computation of updated physiography data, using Sentinel-2 satellite information as input, has been investigated at Met Eireann (Walsh et al, in ASR, 2021[5], and Bessardon et al, EWGLAM-2021 workshop[6]).

In order to understand how ML approaches could be beneficial for core parts of our NWP codes, the ACCORD MG formed a dedicated WG with the aim to deliver a portfolio with suggested R&D topics. The portfolio should contain, per proposal, a description of the existing code or physical-based algorithm currently used in ACCORD, suggest what type of ML algorithm could be considered, and say something about training data sets. A first important action by the WG-ML was to trigger a 2h open discussion with five experts invited in the context of the EWGLAM/C-SRNWP meeting (28 Sept 2021). This discussion, which the WG-ML prepared with input questions for the experts, definitely helped to better understand the challenges for ML in NWP. It was for instance largely suggested that exchanging “straight away” a full physics parameterization block by one ML code cannot be expected (at least not rapidly). The point rather was made that a careful, progressive, evaluation of ML tools for specific sub-parts of a parameterization should be considered to start with. How to choose which sub-components could be appropriate candidates will be part of the next steps for the WG-ML. A robot portrait could be any code component with a significant numerical cost, which represents a fairly well understood process whose input and output information (and data sets) can be well defined. In addition, the use of ML for data assimilation sub-parts will be addressed, in close coordination with the DA Area Leader and the Research Team therein. In the close vicinity to the ACCORD surface assimilation concerns, however outside of the current RWP, the team in charge of developing the offline LDAS system in MF is exploring AI/ML tools for assimilating ASCAT data. The observation operator is then based on an ML tool that links the scatterometer values with some surface fields; current work focuses on the Leaf Area Index. This work finds an echo in the plans recently set by ECMWF on applying NNs possibly in combination with linear statistical methods to Metop/ASCAT data (Weston et al, ECMWF-ESA Workshop on ML for Earth System Observation and Prediction, 2020[7]).

Additional meetings with experts are seriously being considered as well. The WG-ML started in September 2021, and was originally deemed to complete its work by the end of 2021. It is likely that the instruction and the redaction of the portfolio however will require the WG to continue for the first quarter of 2022 (this will be discussed within the WG).

- ***highlights from 2021***

  The forming and the work of the WG-ML in itself could be considered a highlight of the ACCORD efforts this year (!)

  One illustration of how ML tools could be efficiently used for NWP aspects is given below. The figure comes from the Walsh et al paper and shows three versions of a land cover map. The Ulmas-Walsh map was obtained by applying a trained NN tool using Sentinel-2 pixelated imagery and CORINE land cover labels as input. While this “ML-version” does not at first glance provide a significantly different picture from the ECOCLIMAP-SG version, it is shown to be slightly more accurate and it could potentially be updated more frequently (also its resolution could potentially be increased).

4 *https://doi.org/10.1029/2020MS002226*

5 *https://doi.org/10.5194/asr-18-65-2021*

6 *available on-line presentation at http://srnwp.met.hu/*

7 *https://events.ecmwf.int/event/172/contributions/1713/attachments/839/1487/ML-Earth-Obs-WS-Weston.pdf*

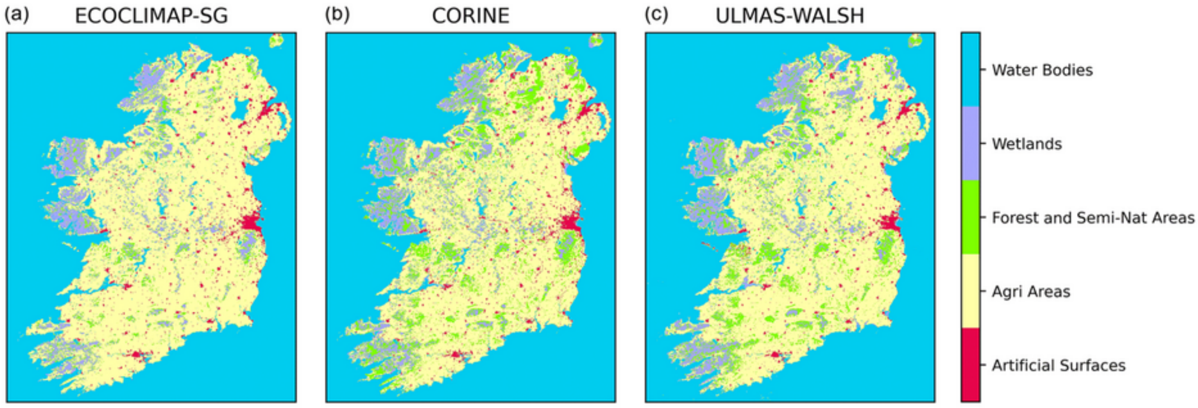


*Figure 3.10.1. Land-cover maps of Ireland: ECO-SG **(a)**, CORINE **(b)** and the UW map **(c)**. Pixel-wise, ECO-SG was found to be 89.9 % similar to CORINE. The UW map was found to be 92.5 % similar to CORINE. From Walsh et al, 2021 (courtesy by Emily Gleeson).*

- ***perspectives and priorities for 2022***

  A very important milestone will be to complete the activity and the deliverables of the WG-ML. A challenging, however motivating target will be to use this input for drafting an early work plan proposal for new research topics in the intersection of NWP and ML. Such translation might require some additional, dedicated brainstorming by motivated teams, WG-ML participants and the ACCORD MG. In parallel, studies on the emulation of a full (or partial) radiation scheme, the implementation of ML tools in the ECRAD radiation scheme (in collaboration with ECMWF) and the elaboration of surface field characteristics from satellite observations are planned to be continued.

4. Summary of manpower status based on figures provided by LTMs (and cross-checked by MG)

4.1. Evolution of the manpower since 2018 until end of June 2021

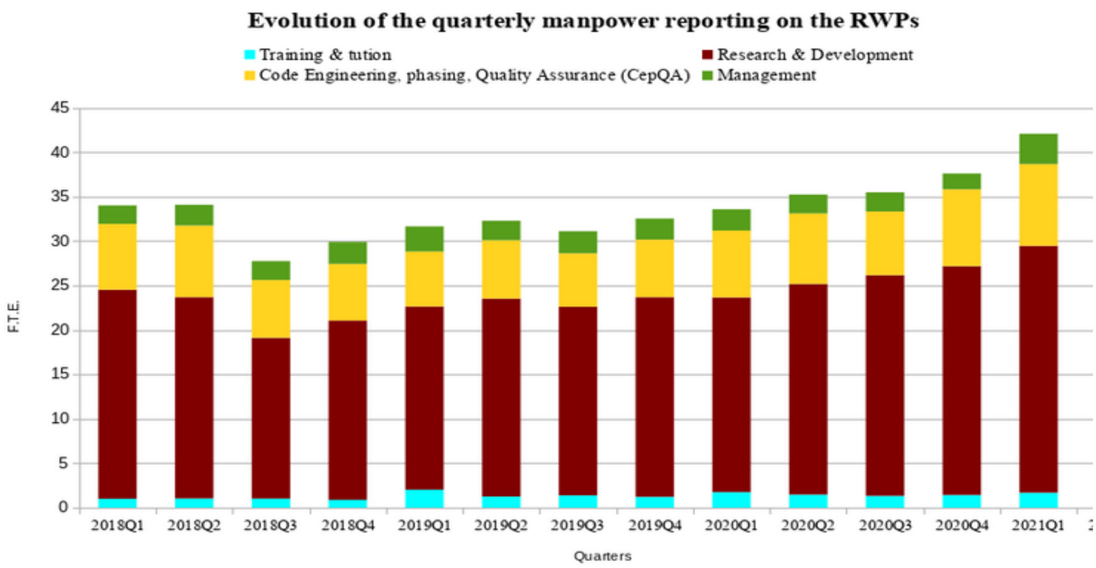


Figure 4.1.1. Evolution of the quarterly manpower dedicated to the Rolling Work Plans since 2018

4.2. RWP2021: commitments and realisation (first semester)

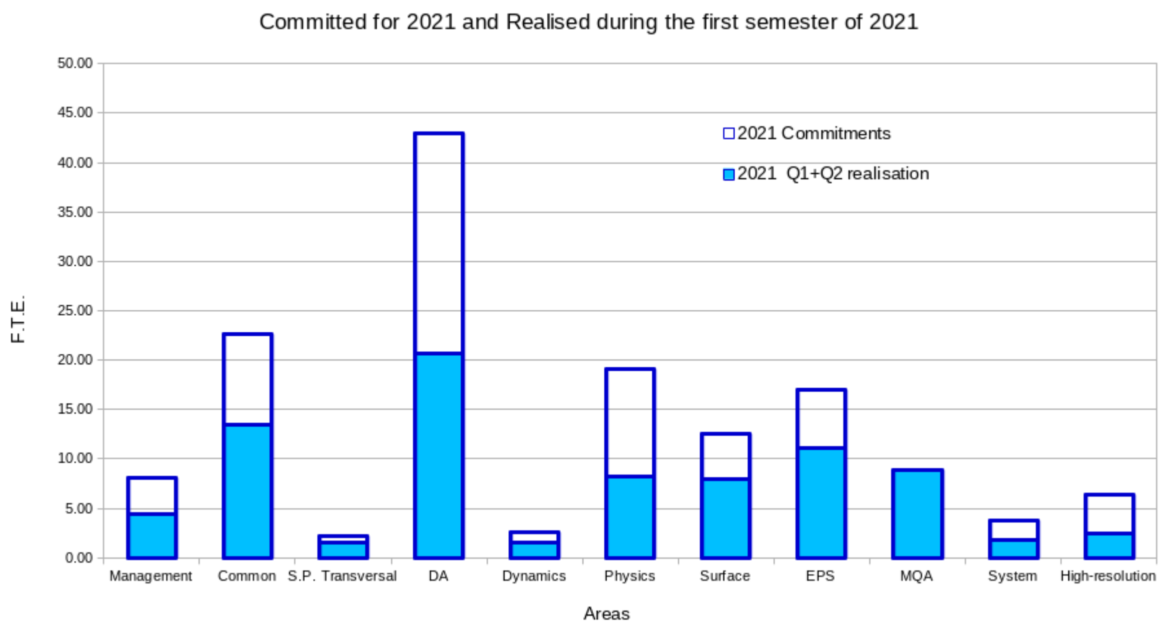


Figure 4.2.1. Commitments in the RWP2021 and work reported during the 1st semester of 2021

4.3. Code Engineering, phasing and Quality Assurance (CEpQA): cycling and technical validation aspects

- An overview of the recently built and upcoming T-cycle R&D releases is provided in Fig. 4.3.1.
- CY48T1 was released on July 7th, 2021. It is the result of the integration of developments from all parties within ACCORD, which details are available here. For the first time, the integration has followed a *"continuous integration"* process, i.e.:
  - Each contribution has been tested through the validation system DAVAÏ, to ensure the sanity check of the code modifications: that any contribution is either bit-reproducible or check that its impact is exactly what was expected (in terms of configurations as well as fields and amplitude);
  - Contributions were merged on-the-flow as they were posted;
  - The result of merges/integrations were tested similarly as the contributions.
- The finalisation of CY48T1 was delayed from March to the end of June, to ensure a more comprehensive validation and correction of two contributions that were producing non-expected impacts.
- The use of the continuous integration enabled an unprecedented level of validation of the declared release CY48T1.
- The planning of CY49 with ECMWF (beginning of the merge in April 2022) then gave us an opportunity to build a CY48T2 beforehand, between summer 2021 and the beginning of 2022. However, to mitigate an expected difficult merge with CY48R1 almost 2 years after CY48, it was decided to restrain the scope of contributions to CY48T2, to "catch-ups" phasings: from operational or pre-operational branches, and from OOPS context. The deadline for contributing these rephasings is set to the end of December 2021. This build is following continuous integration.

- A command-line version of the DAVAÏ validation system has been developed, with a first beta-release in September 2021. Note that the use of a preliminary version of the tool already enabled solving one of the two above-mentioned issues in the finalisation phase of CY48T1.

The beta-release is only ported to MF/belenos for now, but will be on ECMWF new HPCs in 2022.

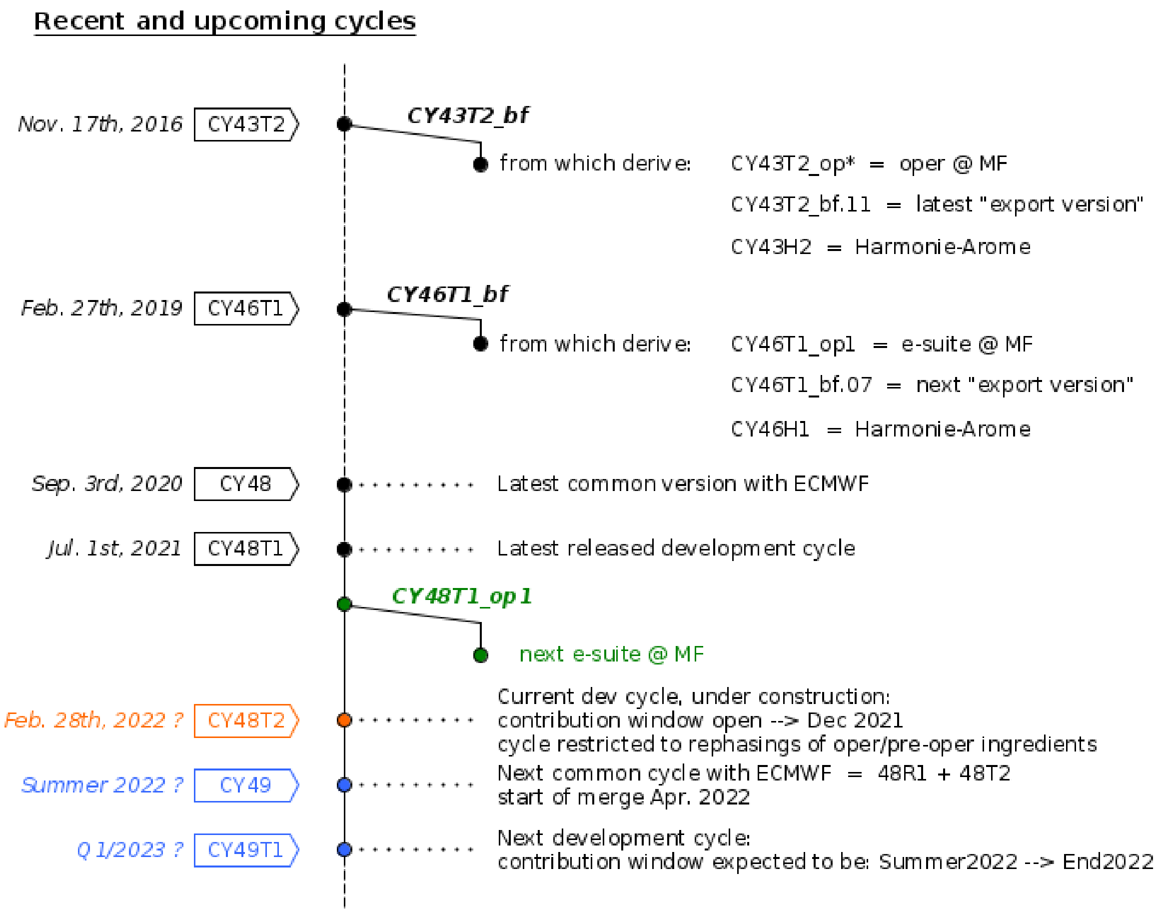


Figure 4.3.1. Overview of the recently built and upcoming T-cycle R&D releases, along with the main derived versions used by ACCORD partners