Execution of Rolling ACCORD Work Plan 2022

A Consortium for COnvection-scale modelling Research and Development

ACCORD Management Group and Support Team

1. Executive summary

As in the previous year, this scientific reporting has been prepared by the full Management Group, as a companion document to the Rolling Work Plan for 2022 available here:

http://www.umr-cnrm.fr/accord/IMG/pdf/rwp2022-approved.pdf .

The scientific reporting document is focussing on specific highlights per Area, complemented by an overview of activity and an outline of the perspectives for the coming year.

Besides the regular, intensive efforts of discussion and coordination across the teams, one may outline a few very specific topics where management and/or scientific efforts have been particularly strong: the kick-off of code refactoring work across a few ACCORD teams (much based on technical expertise provided by MF), the dissemination of expertise and know-how on OOPS for data assimilation, the onset of commonly shared coding efforts for the cloud-aerosol-radiation interaction topic (a kind of flagship topic of across-family and across-CSC collaboration in physics), the concrete testing with an ACCORD source code forge and the dawn of setting up new working methods around the codes. These few "headlines of highlights" should not shed a shadow on the efforts and progress in the other R&D areas of ACCORD, like the implementation of SEKF as operational surface assimilation at one Member institute, the efficient online training on "harp", the use of Stochastic Parameter Perturbations (SPP) in EPS etc.

The reader therefore certainly is invited to scrutinise the several sections of the scientific reporting in order to get a complete picture of the ACCORD R&D activity in 2022.

2. Summary of ACCORD activities in 2022 on Management

2.1. Scientific Management and organization of the MG

The ACCORD MG meets every second Friday for a full online morning meeting (9h to 12h, fairly often 12h30). One might notice that the ACCORD MG held its very first full physical meeting in the premises of RMI on 30 September 2022, after about two years of COVID-related restrictions. All Area Leaders organise very regular topical meetings, following internal working arrangements that each AL has agreed on with the teams. Instrumental documents for the ACCORD-wide management are the Rolling Work Plan (RWP) and the Detailed Action Plan (DAP), whose preparation and follow-on require some substantial and collective effort by MG.

The data assimilation AL, Roger Randriamampianina from Met.Norway, has taken the position of Lead Scientist in DEODE (this is a full time post). Therefore, the DA/AL position has been reopened

in ACCORD with a Call for Application in October-November. The goal is to be able to propose to the Assembly the name of the new AL in the beginning of December.

Another MG perspective is to open the Physics Area Leader position in Q1/2023, after approval of the Physics interoperability roadmap, as well as of the (new) Terms of Reference for this position by the Assembly end of 2022.

Eventually, the position of the Consortium Scientific Secretary will have to be staffed in 2023, as Patricia Pottier (MF) will leave for retirement. The precise steps for her replacement are currently under discussion (MF is investigating whether it can provide a new staff).

2.2. Information and communication

Two ACCORD Newsletters have been produced in 2022. The All Staff Workshop took place in hybrid mode on 4-8 April (in-person in Ljubljana, remote with Bluejeans). ACCORD teams also provide a significant part of the participants to the yearly EWGLAM/C-SRNWP workshop (this year in hybrid mode on 26-29 September, in person in Brussels).

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

The MG has been addressing specific thematics related to the interface of ACCORD-organised R&D with local, operational-oriented activities (using ACCORD codes) in Member institutes. This brainstorming analysis has led the MG to drafting two notes that will be submitted to STAC:

- an overview roadmap listing the goals and milestones that the MG would like to reach, in accordance with the Strategy. The roadmap has intentionally been kept at the level of an overview, listing items but without making timing targets overly explicit;
- a white paper note explaining the views of the MG on specific research-to-application (and reverse) bridging tasks. Three aspects have been studied by MG: testing/validation, users' feedback, documentation. The white paper is constructed as a header note complemented by the three topical annexes. It is deemed to be shared with any ACCORD institute or group of institutes who wish(es) to elaborate on the bridging tasks between ACCORD (provider of common NWP codes) and local teams in charge of the implementation and the use of the codes in forecast systems. As an example, the MG will set up a working group in charge of providing recommendations on how to organise users' feedback at ACCORD-level; this WG will be composed of participants from all families (MF, UWC/Hirlam, LACE, former Aladin-MoU5 members).

Discussions regarding some level of scientific collaboration between ACCORD and COSMO have taken place at the ASW. A few topics of common interest have been identified, where more regular exchange of results could be of mutual interest (stable boundary layers, 3D effects in turbulence, cloud physics). Some organisational topics might be addressed as well in future meetings at consortium management level (perhaps regarding documentation or communication aspects).

A number of ACCORD MG members also play a leading, or a specific, role in the DEODE (DestinE on-demand Extremes digital twin) project. The ACCORD MG expects to continue to maintain informal contacts with specific DEODE WP leaders, especially on topics like code adaptation, the design of very high resolution configurations, and system implementation. Some interaction at the level of the core project management also will be continued (in order to spot opportunities or address risks, or to address legal issues etc.).

3. Activity report per Area

3.1. Strategic program: Transversal software developments (SPTR)

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

This work package consists of 5 tasks, of which the first one ("SPTR1: Prepare ACCORD codes for porting to GPU") is by far the most urgent and important. This is reflected through the fact that all the reported work carried out so far in 2022 relates to this task. Preparing the ACCORD codes to GPU's is a large undertaking with several aspects, which have progressed at different rates.

A first subtopic (SPRT1.1) is the **porting of the spectral transforms** to GPU's. In fact, the spectral transforms already have been ported to NVIDIA GPU's in 2021, but during 2022 this work has continued, with further optimizations of the GPU version (work done in collaboration with NVIDIA). An initial porting of the spectral transforms to AMD GPU's has also been carried out. Another evolution related to the spectral transforms is that ECMWF has moved their (global) spectral transforms to an external open-source repository (https://github.com/ecmwf-ifs/ectrans), which will easen sharing the code with vendors like NVIDIA. Given the large overlap between LAM transforms and global transforms, a similar evolution, or even integration into ECMWF's ectrans package would be highly desirable for the LAM transforms. Work has started in this direction, but the decision to also make the LAM transforms open-source still has to be made.

A second subtopic of the GPU porting is the development of **source-to-source transformation tools** (SPTR1.2) which will allow to transform the existing CPU-targeted code to efficient GPU code. This involves transformations such as inlining of pieces of code, reordering of loops, and adding accelerator directives (OpenACC or OpenMP). Two of such tools are under consideration. The first one is LOKI, which is being developed at ECMWF. Work was done at MetNorway to test this tool on the ACRANEB2 radiation scheme of the ALARO CSC. Several functionalities, such as loop reordering, array promotion and demotion, and the insertion of accelerator directives, have been developed, leading to a LOKI-based GPU version of the ACRANEB2 scheme. In parallel, Meteo-France staff have developed a set of scripts based on the fxtran Fortran parser and successfully applied it to port several ARPEGE parameterizations to GPU. Besides the work on the source-to-source transformation tools themselves, the ACCORD codes also have to be prepared to be processed by such tools. For instance, the names of loop variables and bounds should be consistent throughout the code, and Fortran array syntax should be replaced by explicit loops. As many of the physical parameterizations of the AROME and HARMONIE-AROME CSC's are being shared with the Meso-NH research model at Meteo-France, this kind of code rewriting must be done in close coordination with the Meso-NH team. To avoid a divergence between ACCORD and Meso-NH versions, the physical parameterizations have been externalized and put in a separate repository PHYEX, where a common version is being developed that suits the needs of both ACCORD and Meso-NH. Although this work has progressed significantly, some technical issues remain unsolved, and the integration in the 3D ACCORD model remains to be validated.

The third subtopic concerns the adaptation of the ACCORD code layout to allow for running the model in a hybrid setup, with part of the calculations running on GPU, and others remaining on CPU. This requires to introduce flexibility in terms of parallelization granularity: where the current code only allows for coarsely granular parallelism, with a single top-level OpenMP loop spanning the entire

gridpoint calculations, this should be modified into a layout which allows to run each parameterization in its own OpenMP (or OpenACC) loop. Significant and impressive progress was made on this topic by MeteoFrance staff. Although for now targeted at the ARPEGE global model, the involved refactoring of the code will benefit the ACCORD LAM configurations as well, since these configurations share their higher-level control routines with ARPEGE. Not only was a code layout contrived which allows for choosing between a coarse-grained or fine-grained parallelism at run-time, the proposed solution also limits the impact on the scientific parts of the code. A key ingredient for this achievement is the use of fxtran-based scripts to replace raw Fortran arrays with smart hardware-aware data structures. Refactoring of the ACCORD configuration codes will follow the same strategy.

Notwithstanding the important progress that was made, it should be acknowledged that the porting of ACCORD codes to GPU's is far from being finished. Especially the refactoring of the AROME and HARMONIE-AROME configurations will require more work. At the same time, the approval of the Destination Earth Extremes DEODE project means that additional manpower will become available from the end of 2022 onward. A substantial effort was made already during 2022, through online meetings and working weeks, to keep the ACCORD physics developers informed about the ongoing refactoring, on how it will affect their way of coding, and on how they will be asked to contribute to this work in the future.

- ***highlights from 2022***

The overall strategy for preparing the ACCORD codes for GPU porting relies on 3 pillars: (a) using hardware-specific libraries where possible, e.g. for performing linear algebra operations or fast fourier transforms; (b) using smart data structures at the control layer routines to increase the flexibility of the code; and (c) relying on source-to-source transformation tools to allow for a single code base while still targeting multiple hardware platforms. The highlight from 2022 is that this strategy seems to be realistic. Especially for the case of ARPEGE (stricto sensu not part of ACCORD, but within the same code), it was shown how this strategy leads to a better-organized code, which is flexible in terms of parallel granularity and target architecture, without demanding the scientists to drastically change their way of working.

- ***perspectives and priorities for 2023***

As indicated in the activity overview, many actions have started but require additional efforts to progress further. A substantial amount of manpower is foreseen in DEODE to help carry out these tasks. Most notably,

  - the move of the physics parameterizations to the external PHYEX package should be completed (includes validation!);
  - the ALARO physics will be cleaned and refactored along the lines of the ARPEGE physics. It seems realistic that this task is completed by the end of 2023.
  - the AROME and HARMONIE-AROME physics control routines will be cleaned and refactored to allow for a flexible parallel granularity. Given the uncertainties that still exist on the path to follow, this task will probably continue into 2024.
  - scalability tests on GPU’s of the spectral transforms will be carried out.

3.2. Machine Learning (ML1)

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

  The WG/ML has met in three meetings this year (online). Among other items, it has been addressing the use of ML tools in probabilistic forecasting and ensemble prediction, for the emulation of a turbulence scheme, in parts of data assimilation (surface obs operators, algorithms and model error) and for physiography.

- ***highlights from 2022***

  The preparation of the portfolio has continued with examples of where ML tools could be studied in close connection with the NWP codes (as surrogates, as additional functions, for enhanced scientific possibilities or for optimization of performances), however the portfolio will not be completed by the end of 2022.

- ***perspectives and priorities for 2023***

  the aim for the WG/ML in the next year could be to:
  - resume the WG/ML online meetings and finalize a version of the portfolio
  - discuss and draft recommendations for the exploration of ML tools in ACCORD
  - perhaps as a specific aspect in the recommendations, assess the link with ECMWF (IFS related) approaches regarding code interfaces ("infero"), shared software infrastructure ("climetlab") and databases (in link with European Weather Cloud ?)

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

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

  The WG-VHR has met four times this year. One outstanding topic of discussion was the use of observations for hectometric modelling validation. A draft summary note has been produced, under the lead of the ACCORD MQA/AL and with input by the WG members. In addition, the WG completed an overview table of the user's needs for VHR forecasts as well as an overview table of existing hectometric configuration available in ACCORD institutes (either experimental or operations).

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

  The work on studying ML tools for the update of physiography data is continued at Met Eireann, in collaboration with other ACCORD institutes who have started to become more familiar with the approach. The investigations about the stability and accuracy of hectometric model configurations are pursued in MF, in collaboration with other teams active in the Area of Dynamics (Met Eireann, CHMI). The code to take into account horizontal derivatives in the ACCORD models dataflow has been integrated in CY48T1 and CY48T2 (see also in physics section), and the scientific evaluation of 3D effects using these fields has started in 2022.

- ***highlights from 2022***

  The WG-VHR has been elaborating on aspects such as improvements to the surface and soil cover characteristics, the use of observations for validation, 3D effects in the physics parameterizations (especially radiation and turbulence). These exchanges have served as

background to the preparation of specific side meetings during the ASW2022 (3D effects, surface) and the promotion of ideas and work initiated by some ACCORD members already before 2022, like the use of ML tools to improve physiography (soil cover) data at hectometric resolution using satellite data (by Met Eireann). Such initiatives have been presented at the ASW and also have been considered in the context of the DEODE discussions for the design of the hyper-resolution digital twin.

- ***perspectives and priorities for 2023***
    - finalise the summary document(s) from the WG-VHR work: table of configurations, table of users' needs, overview document about scientific NWP challenges at hectometric scales
    - organise a dedicated WW for hectometric modelling using ACCORD code (the current plan is to organise this WW in February 2023 at SMHI), with a focus on practical exercises for designing ACCORD-based VHR model configurations
    - present the outcomes of the WG at the ASW2023
    - Specific R&D efforts are expected to be organised in the framework of the ACCORD RWP, with the interested teams (like 3D effects in physics parameterizations or improvements of physiography and surface fields characterization). Positive feedback with the DEODE work might be expected (manpower and tasks, validation)

3.4. Dynamics (DY1 to DY3)

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

Our first scientific goal is to update and improve our current dynamical core, semi-lagrangian, spectral and semi-implicit (SISL-ST). It is still quite very efficient and can operate at 500m resolution and probably more. One important aspect of the kernel that might be useful in the following years is the possibility to reduce the spectral truncation that will greatly increase stability and timestep at a moderate loss of resolution. Most of the development occurred in the context of our spectral core :

a) New dynamics options such as a new vertical variable, the addition of a sponge layer at the top or the improvement of the implicit operator by adding a second pressure reference that would allow a better simulation over high-altitude regions. Those developments come from theoretical considerations aiming at improving the stability and accuracy of the spectral kernel. Those options are currently tested on two problematic configurations AROME-Svalbard and AROME-USA and exhibit some problems, work is continuing to solve them.
b) Formulation of Euler equations as the increment of the hydrostatic equations. The aim is to add features of NH behaviour of the modelled flow ("non-hydrostaticity") gradually and omit it where numerical stability is questionable (with vertical or time from start dependency). In parallel, the control parameters are introduced in the linear model enabling to modify it after the linearization from the full model aiming on the improved stability. This code is available on top of cy46T1 and on top of cy48 for constant control parameters (as a GIT branch in Toulouse). Stability analyses and real cases have been carried out, and are in good agreement. What is remarkable about this development is that it allows us to simulate non-hydrostatic features with a good accuracy while keeping only a small part of the non-hydrostatic terms. In the Occitanie case, it was shown that with appropriate control parameters, stability can still be achieved even with a linear system usually not stable.

c) Coupling procedure: the influence of increased coupling frequency (1h), reduction of the lateral boundary conditions (LBC) files size through the frame approach in the LBC files and through the choice of truncation in the LBC files. The frame method has been investigated, it produces forecasts with the same quality but the gain in terms of file size is weak compared to using spectral files. Hence the technique of reducing the spectral truncation such as using cubic truncation has been tested. It produces forecasts with very little quality reduction.
d) The necessity of including the three-dimensional processes like horizontal wind shear and advection to improve the representation of turbulence kinetic energy (TKE) and of turbulence total energy (TTE) in runs with kilometric horizontal resolution was indicated by recently published research. In the frame of this topic the implementation of horizontal features into the turbulence scheme TOUCANS was started. In the proposed solution horizontal shear effects were parameterized using three different approaches and were included in the prognostic equations for TKE and TTE. The formulation is based on the calculation of horizontal derivatives of the two wind components in which we benefit from the semi-lagrangian horizontal diffusion framework. Different possibilities for the computations of the horizontal turbulent length scale have been implemented. Those were carefully looked at on a test case. It is very encouraging to see that there were no problems with numerical instability.

Another potentially promising feature is the possibility to fully work in gridpoint space also for the dynamics (e.g. like for the physics) by implementing grid point operators. This would allow us to get rid of the expensive spectral transforms while implementing a more stable implicit solution. A Phd work on that topic (in MF) was completed in 2021, and it successfully demonstrated how to invert the implicit operator. In addition, some work about multigrid solvers did take place. Little activity has occurred on these topics this year due to lack of resources and prioritisation.

Our last field of research and development is the testing and learning of the new Finite volume dynamics developed in ECMWF (FVM). A local area version has been coded by ECMWF in order to implement a domain specific language developed by colleagues from Meteo-Swiss. We managed to download a recent version of their system and to make some simulations with it. For the time being a recruitment will take place on that topic in the context of the Destination Earth project.

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

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The dynamic work is divided between different services: Météo-France, CHMI, SHMU, Met-Eireann, IRM. Collaboration exists in many respects since the skills on different aspects of the code are shared between different services. In the framework of the Destination Earth project, a more integrated collaboration on specific tasks will take place.

- ***highlights from 2022***

Three activities with important results are highlighted for this year:

a) A step forward concerning vertical finite elements (VFE) with more stable formulations. VFE allows a higher order vertical discretization with possible positive impact in the upper atmosphere.
b) Stable simulations have been carried out at 150m resolution over the Alps. This proves that our kernel can work well at those very high resolutions on a complicated domain.

c) The possibility to perform a simulation showing all the non-hydrostatic features, but with only a few terms is a very interesting research and allow us to renew or view of the non-hydrostatic system (see "Formulation of Euler equations as the increment of the hydrostatic equations" explained above)

- ***perspectives and priorities for 2023***

The new options of the dynamics should continue to be tested on the problematic cases and we should try to solve the problems observed. The formulation of Euler equations as the increment of the hydrostatic equations will also be tested on the same cases to assess some stability improvement.
The main priority will concern the setup of a common configuration at very high resolution (around 200m) that also includes some options that will be able to solve the problematic cases.

3.5. Data Assimilation (DA1 to DA8)

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- ***Overview of the activity in the area***

During the first semester of 2022, a total of 242.25 person months was reported as contribution to data assimilation (DA) work, which is 51.4% of all expected. The two largest parts **DA4** and **DA3**, respectively, 23.2% and 22% are on the improvement of the assimilation or implementation of the known and existing observations in our operational DA system and on the implementation of new observation types (**DA4**). 13.9% 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, 11%, 10.1%, and 7.6% of the reported contributions. The reported contribution for OOPS development is now increased compared to last year (5.3%) providing very good results in local implementation. Only 6.8% 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 **DA5** could be more than 7.6%, since it can be included in both **DA2** and **DA3**. This is the reason why in 2023 some reorganisation of work packages is done.

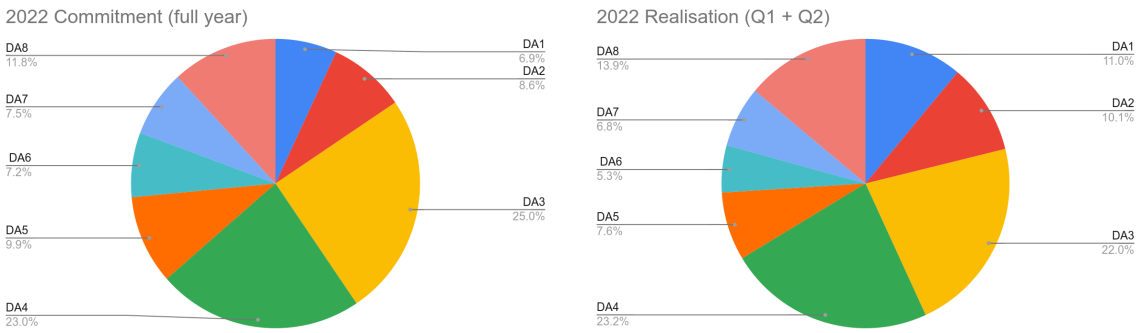

Figure 3.5.1: The reported DA work during the first semester of 2022 per work package.

- ***Organisation of the work within the consortium***

The DA tasks are described in 8 work packages which accomplishment is handled by two groups of research and support teams. The sub-tasks of 13 research and 9 support teams were slightly modified

to avoid RWP tasks being split between too many ST and RT teams. In cases of DA tasks involving more than one team, combined meetings were occasionally held (for example RT2 meetings with also invited participants from RT8). Most of the teams have organised meetings once or twice per year, both virtually and physically. The physical meetings have been devoted both to RT and ST. In addition some sub-group meetings with dedicated research tasks have been held and reported to the relevant RTs and STs. 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). LACE and HIRLAM (and now also the former DAsKIT) have agreed on a common reporting practice within a shared document (https://docs.google.com/document/d/1O82ApzLA-wMjw0bjj6GA2o8537qTRwyRYsAkhpBl89w/edit?usp=sharing). This procedure has made the work and progress transparent and will form the basis for a future coming ACCORD reporting practice, also for areas other than DA.

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

This activity has not yet started.

- ***Highlights from 2022***

We progressed well with the majority of the planned tasks in 2022. These can be divided into algorithmic and observation handling. The algorithmic ones concerned among others pre-operational implementation of 4D-Var, ensemble based algorithms (EnVar and hybrid En/Var), application of field alignment with radars from different countries, exploitation of initialisation techniques and cycling strategies as well as handling of host model information. Dependence of hybrid en/var performance on perturbation and localisation length scales techniques have been investigated. Observation handling progress concerns a more refined use of traditionally used observation types (satellite, radar, aircraft, radiosondes, products, GNSS etc.) and continued exploitation of various crowd-sourced data (netatmo, wow, smartphones etc.) and other novel observation types (InSAR delays, microlinks etc.). Mode-S observations from EMADDC are now massively used and proved beneficial in various applications. Several adaptations towards nowcasting have been applied, including the design of hourly 4D-Var with overlapping windows at KNMI, work with refinements of cloud ingest technique, and investigations of effects of short observation cut-off in Slovakia. In addition, there has been progress with the development and sharing of common monitoring tools (obsmon, Accord DA tools). Here we would like to highlight a bit more five more specific areas of progress: (1) EnVar in the OOPS framework, (2) progress with use of radar data and (3) enhanced use of surface sensitive channels from satellite microwave instruments.

- ➢ The migration to OOPS DA codes and evaluation of new algorithm prototypes progressed rapidly in 2022. The AROME-FR EDA with 25 members (**DA2**) on the cycle 46t1 was made operational in June 2022. This is used to provide initial perturbations used in experimental 3DEnVar and 4DEnVar formulations. An increased ensemble size has been demonstrated to be beneficial to EnVar performances, and a 50-member EDA size is thus planned. OOPS prototypes of 3D-Var and 3DEnVar have been set up, experimented and validated in the context of AROME-France for cycles 43 and 46. Associated experiments were then reproduced successfully by several other ACCORD members, such as ARSO, ZAMG and Met Norway (Figure 3.5.2). Work towards the introduction of traditional TL/AD limited-area 4D-Var into the OOPS framework has been initiated. A 6-month AROME-France experiment demonstrated very significant improvements of 3DEnVar against 3D-Var (Figure 3.5.3). Positive impacts were also observed for several high precipitation events, fog situations and wind gusts during winter storms. This provides strong motivation for operational implementations of EnVar approaches. A major step in 2022 has been the migration of AROME 3D-Var, 3DEnVar and EDA under OOPS for cycle 48t1 at Météo-France. This

included merging screening and minimisation within a single OOPS job, VarBC handling, treatment of radar data, corrections of bugs originating from the "historical masterodb code", OOPS namelist setup using dedicated recipes, adjustment of the json files that define the OOPS configurations, etc. These new OOPS configurations in 48t1 have been successfully validated against the historical AROME 3D-Var version. Associated 3DEnVar experiments with OOPS confirmed improvements which were obtained in previous cycles. The flexibility of OOPS also allows the introduction of hydrometeors in the 3DEnVar control variable, enabling the direct assimilation of radar reflectivities and satellite lightning products. This was found to provide realistic analysis increments of moisture and hydrometeors, and positive impacts e.g. for high precipitation events, compared with the currently used pseudo-observed humidities. 4DEnVar experiments with OOPS are also being pursued, with encouraging results over case studies. First results suggest that the average impact of 4DEnVar, compared with 3DEnVar and using the same observations, is neutral to positive. Additional significant improvement is gained when assimilating observations at 15-minute frequency for radar data, surface stations, ground-based GNSS data and SEVIRI radiances. (**DA6**).

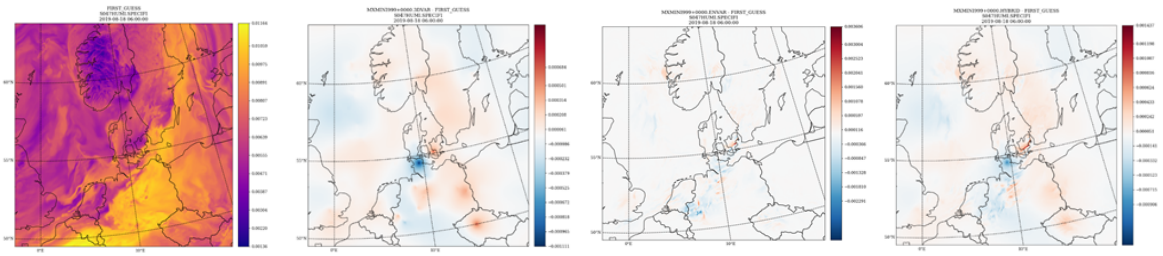

Figure 3.5.2: Low level specific humidity (left) and analysis increments using 3DVar, 3DEnVar and hybrid 3DEnVar, respectively, over the AROME-DK domain and using 20 MEPS members. The 3DEnVar increments are smaller but much more flow-dependent than those of 3D-Var, see the frontal area in the centre of the domain. The hybrid version retains some properties of both algorithms (Benedikt Strajnar, ARSO).

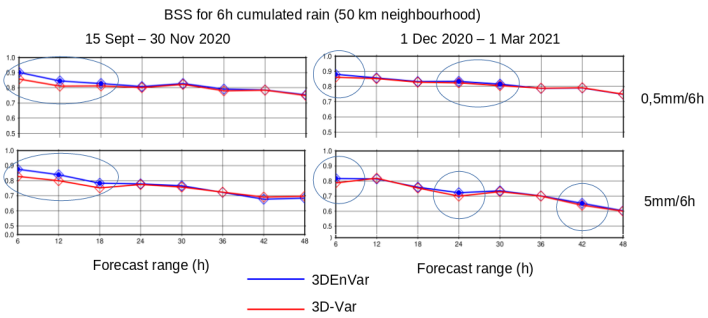

Figure 3.5.3: Brier Skill Score (BSS) for 6h accumulated rain (with 50 km neighbourhood) of 3DEnVar (in blue) against 3D-Var (in red) of the AROME-FR over 6 months. Top and bottom panels correspond to two different rain rate thresholds. Significant differences are identified by full squares (and large ellipses). (V. Vogt and P. Brousseau, Météo-France)

- A wide effort to optimise the use of reflectivity and wind distributed by OPERA included upgrades of the preprocessing methods, improvement of the DA algorithm and investigation of differences and usability of the two different production lines (OIFS vs. ODE). The latter study, carried out by AEMET, DMI and SMHI, was shown to have a significant impact on how the data can be used, especially because the quality estimation of radial winds relies on

the quality indications of corresponding reflectivities. A method for dealiasing (torus mapping) and procedure for creating super-observations were added to the HOOF preprocessing software and are being evaluated. After a strong drying effect was identified in the ALARO CSC over the central-European domains, several possible mitigation strategies were proposed and extensively tested, such as redefining the sensitivity estimation and limiting the use of undetect (dry) observations. Reflectivity is now operationally used in the ALARO-SI hourly RUC. Wind quality was studied over the Nordic and Spanish domain, where substantial issues with the OPERA wind data provided by the Spanish network are being investigated. For MetCoOp radar wind data assimilation was introduced in the operational suite. Reflectivity inversion was tuned in the e-suite of AROME-FR, allowing for better variability in the retrieved pseudo-observations (Figure 3.5.4).

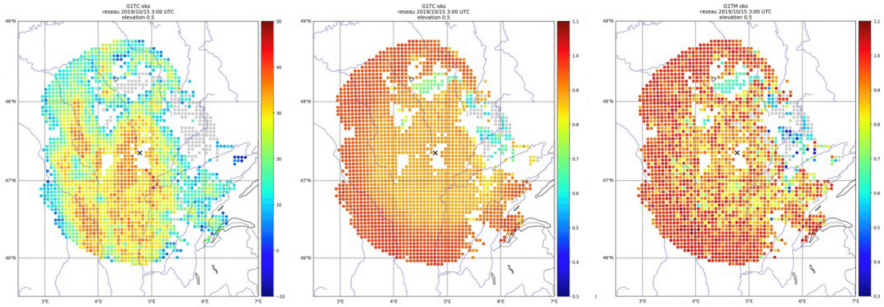

Figure 3.5.4: Observed reflectivities (left) and retrieved relative humidity pseudo-observations with old (middle) and new (right) AROME-MF setup which allows for more realistic retrievals with a better variability more consistent with observations. (Maud Martet, Météo-France).

- The enhanced use of satellite microwave radiances is based on the methodology to estimate the contribution from the surface dynamically through emissivities obtained from a neighbouring window channel. This implies that one can obtain temperature and moisture information from radiances also in the lower atmosphere close to the surface. The methodology is applied to the microwave instruments AMSU-A, MHS, ATMS and there is ongoing work with MWHS-2. The method is already implemented operationally in arome arctic, and more operational centres are planning near future preoperational introduction. The Figure 3.5.5 below illustrates the reduction in bias and standard deviation, when applying the enhanced method, for more than one month of AMSU-A channel 4 (low-peaking) innovation departure statistics.

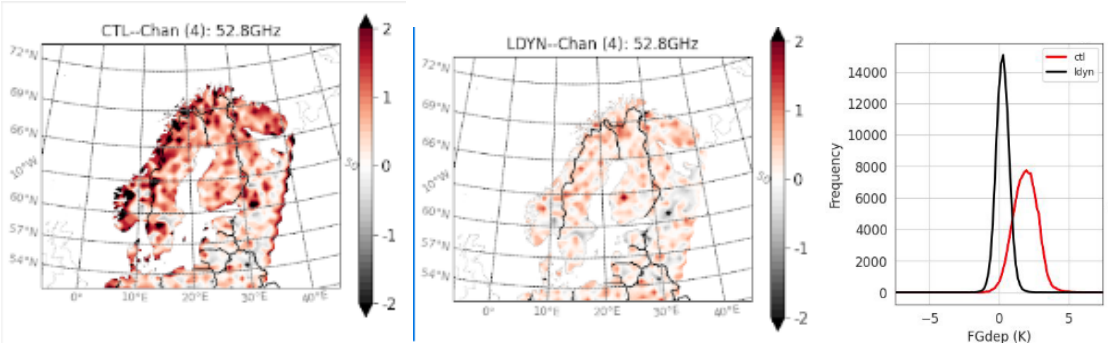

Figure 3.5.5: Spatial map of standard deviation of observation minus first guess departures for AMSU-A channel 4 for reference (left) and enhanced (right) procedure. Histograms of departures accumulated over the domain (left), with red curve for reference and black for improved handling. Departure statistics are for the period 20210110-20210228. (Stephanie Guedj, met.no)

- ***Perspectives and priorities for 2023***

The following tasks will have special attention in 2023:

- ➢ Operational implementation of 3DEnVar under OOPS at Météo-France, through a dedicated real-time e-suite in cycle 48t1; pursue associated evolutions and experimentations with OOPS of 3D-Var and 3DEnVar by other ACCORD members (**DA2/DA6**).
- ➢ Pursue experimentations and evaluations of the 3D/4DEnVar and hybrid En/var formulation under OOPS, including the assimilation of high frequency observations every 15 minutes (**DA2/DA6**).
- ➢ Continue experimentations and evaluations of the introduction of hydrometeors in the EnVar control variable in OOPS, including the direct assimilation of radar reflectivities and lightning satellite data. (**DA6**)
- ➢ Continue exploring DA procedures, settings, and frameworks (for example sub-hourly DA) appropriate for nowcasting applications (**DA1/DA2/DA3**).
- ➢ Continue exploring enhanced use of existing observations for DA by refined handling (all-sky, supermodding, cloud detection, low-peaking channels (**DA1, DA2, DA3**).
- ➢ Continue development and sharing of common diagnostics tools for monitoring of DA functionality (**DA7**).
- ➢ 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 all ACCORD members.

3.6. Physics parameterizations (PH1 to PH7, PH9-PH10)

- ***Core developments on physics (upper-air) parameterizations***

A potentially structural change for the scientific work on the core upper-air physics parameterizations (i.e. turbulence, radiation, microphysics and clouds etc.) has been discussed by the MG in the course of 2022. The proposal is to move away from the CSC-wise scientific coordination towards a process-wise coordination. The first steps in this direction consisted in triggering thematic side meetings during the 2022 All Staff Workshop (3D turbulence, 3D effects in radiation, code infrastructure for 3D, stable boundary layer) and reorganising the Work Package contents in the Physics for the next Rolling Work Plan (2023). This effort should be seen in complement with the outcome of the WG on Physics Interoperability outlined below. In the meanwhile, the scientific coordination and reporting for 2022 remained along the lines of the three CSCs and the several already transversal work packages defined in 2021.

- ***Transversal activities***

The work on the clouds-aerosols-radiation interaction (**PH6**) focussed on the preparation of a CSC-common workflow inside the codes. Three specific coding efforts have been put in place: enable the ALARO-based radiation scheme ACRANEB2 to use near-real-time (nrt) aerosol mass mixing ratios (MMR) (this work assumes a new interfacing of aerosol data with ACRANEB2 and with CAMS nrt data); implement the general MMR dataflow, including the handling of cloud condensation nuclei (CCN) and ice freezing nuclei (IFN) (this is first coded and evaluated for AROME); handling of CCN

and IFN in the HARMONIE-AROME configuration. The teams work towards a single, common, CSC-agnostic dataflow and interfacing to the relevant parameterization schemes (microphysics, radiation). The PH6 co-leads organise regular across-CSC online meetings in order to assess their progress and plans, and ensure the common specifications are met. In addition, single-column model (MUSC) test configurations are also being worked out (this is in close relation to the RWP WP **PH4**). Work to implement a “very " simple surface scheme first in MUSC to validate the atmospheric part of the 3 CSC has been started.

The activity on model output fields (**PH5**) slowed down in 2022. However, it should be noted that a number of ACCORD teams have been benefiting from recent new model output diagnostics, such as precipitation types, available in the CY46T1 release (in this context, the team in CHMI spotted a bug and discussed the fix with the MF contact). Regarding 3D effects in physics, the code infrastructure for handling horizontal derivatives has been completed in CY48T2 including trailing bugfixes with respect to the code in CY48T1. A side meeting was arranged at the 2022 ASW to discuss plans on 3D physics; its outcome mostly materialised in new, specific tasks in the turbulence and radiation work packages of RWP2023.

The new code infrastructure for handling horizontal gradients inside the physics column-wise gridpoint computations paves the way for addressing some effects of 3D turbulence. It should be stressed that this new functionality does not (yet) enable a fully 3D turbulence scheme, however specific effects requiring horizontal gradients are accessible. In this spirit, a master thesis study supervised at MF (S. Gallego, D. Ricard, R. Honnert) aimed at evaluating the impact of additional terms for turbulence as proposed by Moeng etal. (2010) and Moeng etal. (2014) in the presence of strong convection over fairly flat terrain. The study showed that the pseudo-3D augmented turbulence scheme tends to increase vertical fluxes of potential temperature and humidity-related fields (see Figure 3.6.1 a-b), eventually also increasing the intensity of turbulent kinetic energy. A numerical stability analysis had to be performed in order to evaluate the validity range of specific control parameters, illustrating the fact that the additional terms can have an impact on the numerical properties of the model. Two case studies of heavy convective rain events have been evaluated, by both qualitative and quantitative approaches, in an AROME-1.3km configuration. These very preliminary evaluations are considered positive and encouraging to continue the investigation of this methodology.

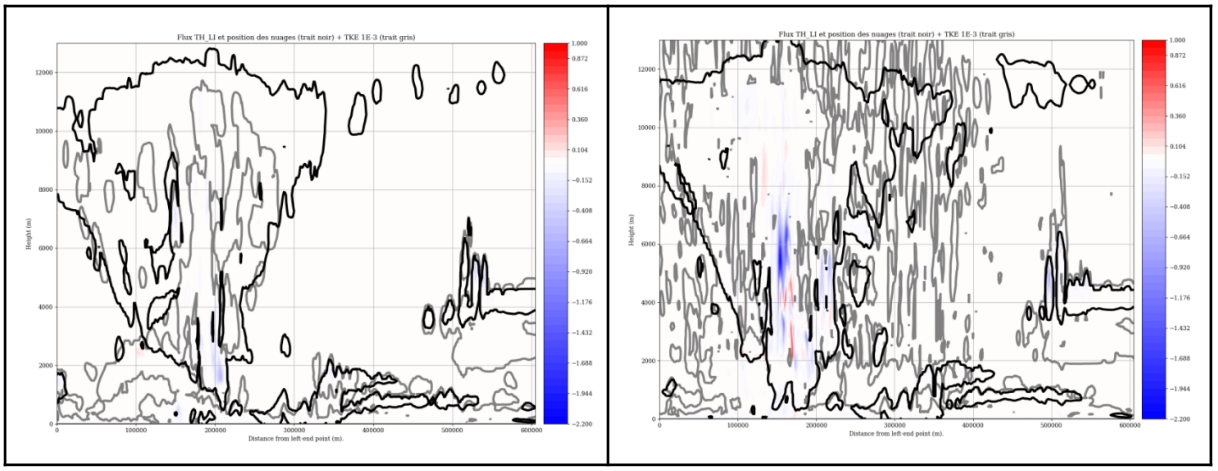

Figure 3.6.1. Vertical slice of the vertical flux of potential temperature $\overline{w'\theta'}_{li}$ in Kms^{-1} (a) [left panel] reference model version with no additional term involving horizontal gradients; (b) [right panel] model version with the additional terms and specific tunings especially with respect to ensuring numerical stability. Courtesy by Gallego, Ricard and Honnert (Météo-France).

References to the pseudo-3D method following the works by Moeng:
C.-H. Moeng. A closure for updraft–downdraft representation of subgrid-scale fluxes in cloud-resolving models. Mon. Wea. Rev., 142 :703–715, 2014.
C.-H. Moeng, P.P Sullivan, M.F. Khairoutdninov, and D.A Randall. A mixed scheme for subgrid-scale fluxes in cloud-resolving models. Journal of the atmospheric sciences, 67 :3692–3705, 2010. doi : 10.1175/2010JAS3565.1.

Research work on stochastic physics (**PH10**) has continued in the framework of a PhD work. The random parameter perturbations approach has been studied in the microphysics and radiation schemes of the AROME CSC. Perturbation strategies for two parameters involved in the cloud droplet distribution function (the cloud droplet number N0 and the shape parameter ν) have been evaluated using 1D simulations. The methodology also addresses the removal of undesired biases in cloud liquid variables due to non-linear effects (an illustration of which is shown in Figure 3.6.2) as well as the elaboration of consistent perturbations of microphysics parameters in the radiation scheme. To resolve the occurrence of biases, an inverse statistical approach is proposed and evaluated in the 1D simulation context.

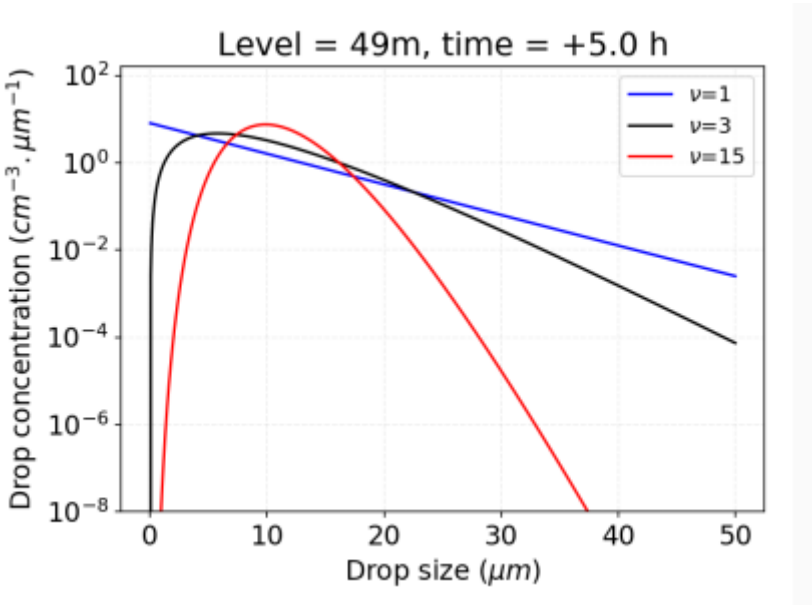

Figure 3.6.2. Droplet concentration in a 1D model simulation as a function of the droplet size for varying shape parameter ν. The droplet concentration maximum increases with ν while the tail of the distribution is reduced; thus, the mean drop size decreases when ν increases, illustrating non-linear effects when using a parameter perturbation method. From A. Fleury (Météo-France), ACCORD EPS working week, April 2022.

An alternative approach, namely process-oriented perturbations, has been evaluated for the adjustment to saturation calculation, shallow convection and turbulence schemes in AROME. Process-oriented perturbations are then compared with more traditional methods of model perturbations like SPPT, and it was shown that indeed the type of spread obtained in both methods is fairly different in nature. A complementary use of both such approaches could be considered in future. Again, the comparison was performed using a 1D model tool and with dispersions from LES as a reference.

Available references to the PhD work are:
Bouttier, F., A. Fleury, T. Bergot and S. Riette, 2022: A single-column comparison of model error representations for ensemble prediction. Accepted for publication in *Boundary Layer Meteorology* in Dec 2021, published online on 23 Jan 2022. https://doi.org/10.1007/s10546-021-00682-6 (ACL)
Fleury, A., F. Bouttier and F. Couvreux, 2022: Process-oriented stochastic perturbations applied to the parameterization of turbulence and shallow-convection for ensemble prediction. Quart. J. Roy. Meteor.

Soc. 1-21. Accepted on 16 Dec 2021, Published online 1 Feb 2022. https://doi.org/10.1002/qj.4242 (ACL)
Axelle Fleury's talk given at the ACCORD working week on EPS and model perturbations available on the ACCORD wiki site (25-29 April 2022, Innsbruck and online): https://opensource.umr-cnrm.fr/attachments/4478/ACCORD-EPSWorkshop2022_AFleury.pdf

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

The WG has been discussing and drafting a physics interoperability roadmap (**PH9**) which will be submitted to STAC and to the Assembly for approval at the end of 2022. The roadmap provides a set of general guidelines regarding the evolution of the physics codes, however it also stresses our intention of promoting significantly more across-CSC collaboration and encouraging exploring physics for hyper-resolution models (hectometric scales). The WG also organised meetings with scientists of all CSCs, alone or (more often) in association with the SPTR Area, in order to explain the WG's analysis and proposals regarding code refactoring.

In the summer 2022, the drafting of the roadmap had well progressed, and in parallel the WG has been discussing the possibility of reopening the position of the Physics Area Leader in ACCORD (addressing the overall context within the consortium, the link with the interoperability roadmap, discussing draft Terms of Reference of a Physics AL position taking into account about two years of ACCORD consortium activity). As an outcome, the draft ToRs for the Physics Area Leader position also will be submitted to STAC and then to the Assembly, in association with the roadmap. If approved by the Assembly, the position would be opened in the beginning of 2023.

- ***Short summary of highlights for 2022 per CSC***

➢ **AROME**

The current operational version of AROME in MF has 1.3km horizontal resolution and 90 vertical levels (lowest model level at 5m). The probabilistic system (Arome EPS "PEARO") now has the same grid as the deterministic Arome-France (CY46T1_op1). In ACCORD member institutes, the horizontal resolutions are spread between the "old" value 2.5km and the recent value 1.3km.

The next e-suite Arome system in MF is planned with the code base CY48T1 and will see the transition of all data assimilation systems to OOPS. In Arome-France, the goal is to implement 3DEnVar (3D-Var will remain in AEARO) and to use aerosol and ozone climatologies from CAMS. The size of the Arome EDA (AEARO) should be increased from 25 to 50 members with a 3.25km resolution.

Several horizontal gradients required to activate some "pseudo 3D effect" (Göger and/or Moeng) are now available in a Météo-France development branch based on cy48t1. This "package" will be used to evaluate the impact of these "pseudo 3D effects" in AROME-MF especially over the Alps but also in a dedicated domain defined for the TEAMx project around the Innsbruck valley at several resolutions 1.3km, 500m and 200m. These domains will be used by the 3 CSCs in the DEODE framework to define "optimal" physics and dynamics options. Work on horizontal mixing length will start across the CSCs for the "Göger term".

Work to enable the use of the MERCATOR-SST in AROME-FR has started.

➢ **ALARO**

The ALARO physics package is used in probabilistic and deterministic forecasting systems with horizontal resolutions ranging from 1 to 8 km. The operational suites are undergoing changes to the new export version. Most recent developments include:

- Research of coupling with surface with respect to taking surface data from updated databases as well as coupling with SURFEX. Right now it is not possible to reproduce ALADIN ISBA results using ISBA from SURFEX.
- Single column model experiments using the MUSC tool can be performed with ALARO if all required input is provided in the input file.
- Radiation code of ACRANEB2 underwent transformation of externalised treatment of aerosols as well as adaptation for better use in single precision.
- Work on turbulent mixing length is almost finished, with numerous choices available as options in the code. However, work on the TOUCANS turbulence scheme is broadened with horizontal shear terms and computations of unresolved vs. resolved turbulence. Fully stable treatment of both prognostic turbulent energies is studied.
- Microphysics has been enhanced with fully prognostic graupel in recent years which enabled development of lightning diagnostics.
- Deep convection scheme that allows for partially resolved and partially parametrized precipitation producing convection in the model is enhanced by a subgrid draft.
- Recent work and development results were discussed during dedicated ALARO working days with plans for future developments.

➢ **HARMONIE-AROME**

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

- MUSC studies showing the sensitivity of modelled fog development to both cloud droplet number concentration and the assumed shape parameters of the cloud droplet size distribution (Contreras et al. 2022). These sensitivities are being explored further in the context of SPP perturbations for HarmonEPS, and with the assistance of the URANIE toolbox (developed in ESCAPE2, VanderGinderachter).
- Many studies on hectometric model configurations, comparing model behaviour against LES models and high-resolution boundary layer observations, or assessing the impact of different configuration choices on e.g. LBC handling, domain size, vertical resolution, and settings in dynamics, shallow convection and urban parametrizations.
- Progress in preparations for physics parametrizations suitable for hectometric scales:
    - (1) start with quasi-3D modelling of cloud shading effects on radiation with the ECRAD scheme and machine learning;
    - (2) investigation of how well a gradual shutdown of parametrized convection at horizontal resolutions approaching O(100m) can be enabled through the introduction of a scale-aware convection length scale;
    - (3) selection and start of implementation of an intrinsically stochastic turbulence parameterization in Harmonie-Arome (Shapkalijevski, review paper in preparation for WAF);
    - (4) Developing ideas for how to deal with turbulence under stable boundary layer conditions under conditions of strong surface heterogeneity (e.g. in urban areas), by new modelling approaches to tackle the roughness sublayer.

- ***perspectives and priorities on transversal topics for 2023***

  On the transversal topics in Physics, the goals may be formulated as follows:
    - The position of the Physics Ara Leader is expected to be opened at the end of 2022 ACCORD Assembly, in close relation to the approval of the physics interoperability roadmap. Should this procedure be confirmed, and an AL is found, then he/she will be

in charge of further implementing the new organisation of the physics area at ACCORD-level.

- work on 3D effects in physics is expected to be continued.
- Studies at the intersection of physics with surface processes (and their modelling) as well as with dynamics (accuracy, stability) are expected to be continued, especially for VHR configurations and in association with the efforts to be undertaken in the DEODE project.
- further progress on the implementation of a CSC-common dataflow and interfacing for cloud-aerosol-radiation interaction is expected (however it is not yet clear whether this code could make its way into an official T-cycle already in 2023).
- part of the physics teams will support the efforts for code refactoring, and it is likely that the physics developers will have to confront themselves with the new coding paradigms, even if only in development branches of the ACCORD codes.

3.7. 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. Last year's report, 2021, described the status and progress in these topics in an overview manner. This year's report builds upon that overview and presents more specific progress in these topics during the last year.

Surface model:
In LACE work on coupling of ALARO-CSC with SURFEX has continued during the last year but some issues still remain to be understood and solved. In Austria promising SURFEX results with reduced bias in 2m temperature and relative humidity have been achieved by activating a combination of ECOCLIMAPv2, prognostic LAI with 12 patches and switching off the canopy scheme. Investigations to pinpoint the biggest reason for improvement will continue.

For the HARMONIE-AROME CSC cy46h the evaluation has been intensified the last year of the full combination of multi-layer surface physics (diffusion soil, explicit snow, MEB) in combination with SODA/SEKF surface assimilation and titanlib/gridPP surface analysis. The multi-layer physics itself shows good potential and rely less on surface assimilation than the more simple surface setup with ForceRestore/D95. The development of the roughness sublayer parameterization for energy exchange over rough surfaces has now entered an evaluation phase and shows promising results. For the sea surface the different ECUME schemes are still critically examined since excess cloudiness has been identified and needs to be better understood.

For the AROME CSC at Météo-France most work last year was technical work due to the change of SURFEX version (v8.0 to v8.1). Work is also ongoing to replace the use of OSTIA by Mercator to initiate the SST. It is part of a larger work which aims to activate the CMO scheme (couche de mélange océanique : oceanic mixing layer) to have a prognostic SST.

Physiography:
At Met Éireann work has continued to apply Machine Learning methods for the development of high resolution, O(50m), and high quality physiography maps to be used for NWP/SURFEX limited area setups over Europe. A methodology to proceed has been developed and this methodology is now followed in further development steps.

ECOCLIMAP Second Generation is used operationally by the HARMONIE-AROME CSC and has been evaluated the last year for the AROME CSC. In the latter near-surface improvements are identified but also a problematic lower atmosphere warm bias during summer. Work is ongoing to better understand the reason for this warm bias.

For ECOCLIMAP Second Generation problematic gaps in the parameter databases of LAI and albedo have been identified in different applications, especially for high-latitude domains. The SURFEX team has recently released updated databases which will help to limit the problems with undefined parameter values for small model domains. In parallel Nordic ACCORD colleagues are working on complementation of the ECOSG parameter databases for high latitudes with the use of other external databases.

Data assimilation:
On the algorithmic side with Simplified Extended Kalman Filter (SEKF) a wonderful step forward was taken during the last year by the AROME team in Hungary where their operational setup based on SEKF assimilation for surface control variables was released. Similar applications with SEKF, still in pre-operational mode or under evaluation, exist for HARMONIE-AROME model domains. SURFEX/SODA offline setups are also under development or evaluation in ACCORD where SEKF is used to assimilate satellite products of LAI and Soil Water Index. In the LAI case the prognostic A-gs option of SURFEX is used.

Satellite products of snow are increasingly used by our NWP community. For HARMONIE-AROME H-SAF snow extent has been already applied in Arctic reanalysis and Cryo product are under evaluation. At Météo-France H-SAF is under development both for snow assimilation in both AROME and for Arpege.

Examples of surface assimilation of other satellite observations are the PhD thesis work and paper by Zied Sassi at Météo-France which deals with assimilation of SEVIRI land surface temperature in AROME by OI algorithmic and developments of SODA EnKF in Norway with the ensemble from perturbed forcing data applied to soil moisture products.

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

The surface leaders have agreed that we arrange one surface working week per semester at ACCORD level, the spring one in-person and the autumn one online only. Last May, in Budapest, the week was arranged in the form of a SURFEX training with NWP focus. We had 12 on-site participants and more than 30 online. The autumn online week will take place at the end of November. In addition the surface area has online monthly meetings on the third Tuesday of every month.

A very concrete step towards increased code collaboration in ACCORD SURFEX development has been taken during the year with the establishment of the SURFEX NWP Github branch. All ACCORD SURFEX developers are invited as contributors and the merging process of different contributions has started. The intention is that this branch will represent one route of SURFEX input to the release of cy49t.

- ***highlights from 2022***

Operational implementation of SEKF in AROME-Hungary

Since June 2022 SEKF replaces OI for the surface assimilation in the operational NWP system of AROME-Hungary. Tests before that show e.g. that the OI and the SEKF setups perform similarly for 2-meter temperature and dewpoint during daytime, while SEKF improves the nocturnal forecast errors (Figure 3.7.1).

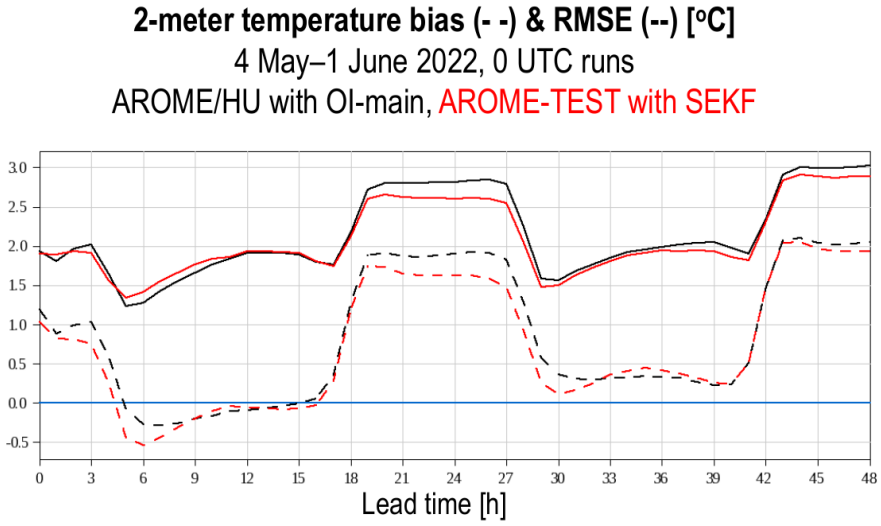

Figure 3.7.1. Courtesy by Helga Tóth and Boglárka Tóth (HMS-OMSZ). See also their article in the ACCORD Newsletter 3.

Events with daily precipitation exceeding 7 mm were overpredicted by the operational OI setup and this improves in the SEKF setup. Less false alarms occurred with SEKF for almost all thresholds, and overestimation of the intensity was reduced.

Progress with surface multi-layer physics

The replacement of the old working horse pair, Force-Restore soil and D95 snow scheme, with the multi-layer physics package including 14-layer diffusion soil scheme, 12-layer explicit snow scheme and Multi-Energy Balance for the forest vegetation is a huge and tedious process. However, good progress has been made during the last year. In the HARMONIE-AROME CSCS (cy46h) the multi-layer setup has started to be systematically evaluated over the MetCoOp, Irish and Spanish NWP domains. The results so far show quite a few improvements and very interestingly is that the role of the surface assimilation is much reduced since the physical processes perform better themselves. However, as usual, a few issues still remain to be understood and solved before a fully operational setup can be achieved.

Assimilation of satellite retrieved land surface temperature in AROME

For work towards a PhD thesis Zied Sassi at Météo-France has a manuscript under review describing assimilation of satellite retrieved land surface temperature in the AROME CSC. SEVIRI retrieved land surface temperature is analysed by CANARI and fed to the soil OI scheme as an additional analysis increment. Results show nighttime improvement in temperature and humidity forecasts up to 36h in lower atmospheric layers.

Towards high-resolution and high-quality physiography for Europe

Land cover in ACCORD is operationally based on ECOCLIMAP 1st (1 km) and 2nd (ESA-CCI land cover 300 m) generations. The 2nd generation one comes with parameter maps (LAI, albedo, …). Lately efforts have been made to complement these parameter maps for the Arctic area where many parameters were missing in the original maps. Also, during the last year work on alternative land-cover databases by Geoffrey Bessardon et al. at Met Éireann has been intensified for a couple of reasons: (i) to overcome the issues with ESA-CCI land cover as reported last year (e.g. too homogeneous) and (ii) the need for even higher resolution O(50-100 m).

Geoffrey states that many options are available and new maps are appearing regularly however, none of the maps have the same labels as ECOCLIMAP-SG and no existing land-cover product can be set as a substitute to ECOCLIMAP-SG without modifications. He also concludes that Machine learning maps are of higher resolution and are quite accurate. Geoffrey has suggested a framework for how to combine different sources of land cover to achieve high-resolution and high-quality land cover for Europe, flexible enough also for future data input.

Introducing a daily updated Leaf Area Index in a NWP setup

The Hungarian team has developed a combination of SURFEX offline and ACCORD NWP online system where daily updated LAI values are fed into the online system. The SURFEX offline system is run with a full number of patches and with the A-gs prognostic LAI option activated. The SEKF SODA algorithm is used to assimilate satellite estimated LAI from Proba-V and Sentinel-3 OLCI. The offline LAI is averaged over patches once per day and replaces the nature LAI value in the online system. Validation of the system has been done for July 2021. Results show that SURFEX ISBA-Ags is able to reproduce LAI anomalies and that these anomalies can influence weather forecasts.

Roughness sublayer - continued development for SURFEX

The Harman and Finnigan (2007) formulation of the roughness sublayer (RSL) over tall vegetation has earlier been implemented and developed in SURFEX and now, during the last year, been further evaluated. 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. Offline evaluation for four ICOS tower sites confirms improvement in flux-gradient relationships over forest. Largest effects are seen for friction velocity and wind above canopy (diagnostics).

- ***perspectives and priorities for 2023***

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

Surface model:
The ongoing work and development of setups with multi-layer surface physics will continue with high priority and hopefully some setups will be mature enough to become operational.
Evaluation and improvement of the Roughness sublayer parameterisation will continue.
Stable boundary layer studies and implementations: Tests with turbulence scheme options and different resolutions will continue. Study is planned for better understanding of physics itself, and how it is reproduced in the model, with use of observations (e.g. Sodankylä).
ECUME scheme testing: this task was almost finished in 2022, but new flux observations appeared from the EURECA project, from the measurement campaign over the sea. Also, the new method was suggested in literature, which allows evaluation of parameterization as such. This was a booster for further activities. New results are expected in 2023. Hope to improve forecasting of fog over sea.

Plans to continue to study the impact of activating the CMO scheme for SST estimation in AROME CSC.

Physiography:
ML methods in physiography: intensive developments will start also inspired by urgent needs from very-high resolution setups.
AROME CSC plans to replace ECOCLIMAP-v1 by ECOCLIMAP-SG. Work has been initiated and seems promising except that we have a warm biais in the low atmosphere.

Data assimilation:
Implementation and validation of OI analysis (SYNOP) in coupled ALARO-SURFEX, further tuning of soil moisture initialization.
Increased application of satellite products in SEKF (LAI, SWI, LST, snow extent).
Initialization of SURFEX through an offline version forced by high resolution near-real time analysis.
Developments to assimilate the H-SAF (snow barrels) and Cryo products on snow extent will continue. Hope to have them operationally in MetCoOp and AROME CSC.
Towards strongly coupled DA: after the discussions, developments and experimenting will start.
Developments over a new spatialization scheme for the 2D part of Canari: Sophie Marimbordes has recently started a PhD to work on the development of a new tool based on ensembles (2D-EnVar) to spatialize 2-metre variables in Canari.
Developments to assimilate satellite observation for land surfaces (surface temperature, soil moisture).

3.8. Ensemble forecasting and predictability (E6 to E12)

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

  For 2022 the tasks have been rearranged in work packages that are not CSC-dependent. That is, the old E1-E4 have been replaced by the new E8-E12 work packages (see below), while the post-processing work packages E6-E7 have been kept.

  - **E6: Ensemble calibration**, including
    - Calibration, including seamless forecasts from analysis to medium-range
    - Generation of large number of ensemble members by deep learning approaches
  - **E7: Develop user-oriented approaches**, including
    - Develop products for meteorological forecasters targeted at warnings for high-impact weather
    - Develop products that use ensemble forecasts for downstream applications such as aviation, dispersion modelling, road weather and renewable energy
    - Continued development of analog calibration method
  - **E8: EPS preparation, evolution and migration**, including

    Preparation of EPS versions which have subsequently led to operationalisation of:

    - 1.3km AROME-EPS from Météo-France
    - AROME-EPS for French oversea domains
    - SPP in MEPS ensemble from MetCoOp
    - COMEPS and IREPS upgraded to cy43h2.2

    Migration to ECMWF's new Atos HPC:

    - A-LEAF and C-LAEF

- **E9: Model perturbations**, including
    - Stochastically perturbed parameterizations (SPP) implemented and tuned in several EPS configurations
- **E10: Initial condition perturbations**, including
    - Work towards merging EPS initial conditions and ensemble data assimilation
    - Development of LETKF for EPS initial conditions
- **E11: Surface perturbations**, including
    - Use of SPP methodology for surface parameters, e.g. for the vegetation thermal inertia coefficient (CV)
    - Perturbation of soil wetness index instead of soil moisture as the latter can be perturbed beyond wilting point or saturation which has been shown to lead to a significant drying of the perturbed members
- **E12: Lateral boundary perturbations**, including
    - Testing whether lateral boundary conditions provided directly by a global EPS are optimal

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

  Much of the development in EPS depends on the configuration of the model system, including the scripting system around the model, and so developing common code is not straightforward. So for the moment we may have to develop the same type of perturbations (e.g. SPP) for each CSC. However, the development is already based on an exchange of code and ideas, for which participation in working weeks and scientific visits are strongly encouraged. The first in-person ACCORD EPS working week was held in spring in Innsbruck which brought together researchers from all ACCORD families. Program and presentations are available on the ACCORD wiki at https://opensource.umr-cnrm.fr/projects/accord/wiki/Innsbruck_25-29_April_2022

- ***highlights from 2022***

  The high-resolution AROME-EPS suite has become operational on 30 June 2022

  In 2022 the horizontal resolution of AROME-EPS has increased from 2,5km to 1,3km. This convergence toward the deterministic system resolution also allows for an increase of ensemble size from 16 to 17 members, including 16 perturbed members and a control member provided by the deterministic forecast. Moreover, this new version of AROME-EPS benefits from the upgrades of the other NWP systems, with improved initial conditions, a new Arome physics package and enhanced high-resolution ARPEGE-EPS LBCs. The performances of this high-resolution AROME-EPS have been evaluated over several months and show significant improvements (Figure 3.8.1). Operational production of Extreme Forecast Index (EFI) and Shift Of Tails (SOT) will follow in the forthcoming months in order to anticipate the risk of high-impact weather.

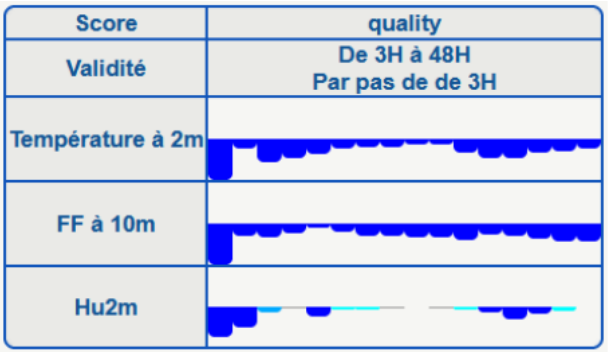

Figure 3.8.1. CRPS difference between 1,3km and 2,5km AROME-EPS as a function of forecast lead time. Blue bars indicate statistically significant improvement. Courtesy by Laure Raynaud (Météo-France).

Stochastically Perturbed Parameterizations (SPP)

SPP was implemented in a C-LAEF e-suite with SPP model perturbations for the summer period 2022:

- 13 parameters (2 in radiation, 5 in microphysics, 3 in turbulence, 1 in diffusion, surface and shallow convection parameterization) are randomly perturbed by SPG pattern generator
- A lot of tuning of perturbation ranges, patterns, etc. was necessary
- Good verification scores – for many parameters better than the operational C-LAEF hybrid perturbation scheme
- Operationalization planned on new ECMWF Atos-HPC

In HarmonEPS, SPP was further developed and became operational in the MetCoOp ensemble on 30 August 2022. As reported last year, and in Frogner et al. (2022; https://journals.ametsoc.org/view/journals/mwre/150/4/MWR-D-21-0099.1.xml) SPP could lead to a bias change for the ensemble members compared to the control. This is now alleviated by the introduction of a uniform distribution for the perturbation values for some of the parameters, while others are perturbed based on the original log-normal distribution. To date 18 parameters are implemented in SPP, however a sub-set of 5 is currently used in the operational MetCoOp ensemble. This subset was chosen to speed up operationalisation while the other parameters are being further worked on. The cost increase in the MetCoOp ensemble from SPP is only 0.3%. The main impact of SPP is to allow the model to develop in different directions and thereby increase the spread of the ensemble. This gives a better agreement between the spread and the root-mean-square error of the ensemble mean (referred to as "skill"), an example is shown in Figure 3.8.2.

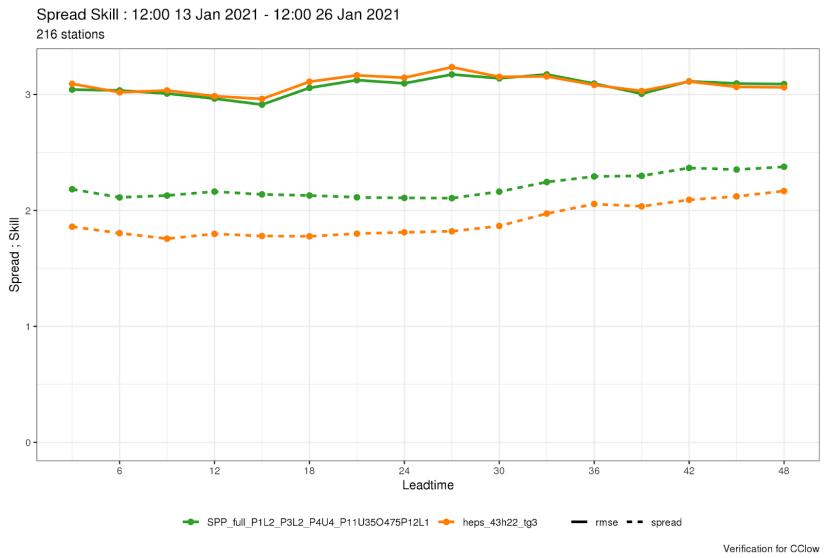

Figure 3.8.2. Spread (dashed) and skill (solid) for total cloud cover for 14 days in January 2021. The reference run without SPP in orange, and with SPP in green. Courtesy by Inger-Lise Frogner (Met Norway).

Perturbation of soil moisture

There has been a long standing issue with drying of the ensemble members that originated from the perturbations of soil moisture. A solution has been found which means to perturb in soil wetness index space (SWI) instead of directly perturbing the soil moisture. The perturbations of SWI are additive perturbations instead of multiplicative as for soil moisture, and we only perturb in grid points where all perturbed values of SWI are no closer than one standard deviation to 1 (field capacity) or 0 (wilting point). If one of the perturbations is outside these limits, all members are given the control value of SWI in that grid point. We consequently avoided the asymmetric distribution of RH2m in the ensemble, but this also reduced the spread, although it is better than turning off soil moisture perturbations which was necessary in operations to avoid the drying. Also, the spread that came from the original soil moisture perturbations originated to a large part from the bias of the members compared to the control, which is spread for the wrong reason (systematic, not random).

AI for analysing and enhancing AROME-EPS

State-of-the-art AI methods have been leveraged to extract useful information from the AROME-EPS members, that goes beyond the classical probabilities/percentiles products. Based on pattern recognition algorithms, an experimental product summarizing the risk of bow echoes in the Arome forecasts has been subjectively evaluated by forecasters during summer 2022 (Figure 3.8.3, method and products detailed in https://journals.ametsoc.org/view/journals/aies/1/2/AIES-D-21-0010.1.xml).

A research project has also started to explore the potential of combining physical modelling and deep generative statistical models in order to enhance the size and resolution of the AROME-EPS. First results are promising.

Statistical post-processing and user-oriented applications

- SAMOS (standardized anomaly model output statistics) and GEMOS (Global Ensemble Model Output Statistics) have been implemented at ZAMG to improve direct model output especially for customers
- Implemented for 2m temperature and relative humidity, precipitation and 10m wind speed

- Verification shows that SAMOS/GEMOS is able to improve the BIAS of the EPSs significantly and is also able to correct the under-dispersion
- SAMOS/GEMOS is providing spatial forecasts and offers a seamless forecast from analysis over short-range to middle-range forecasts (combination of several deterministic and ensemble models)
- An example is shown in Fig. 3.8.4

Several collaboration works are ongoing in order to use the AROME-EPS as inputs for downstream applications, including irrigation models, atmospheric dispersion of pollutants, air traffic management and renewable energy production.

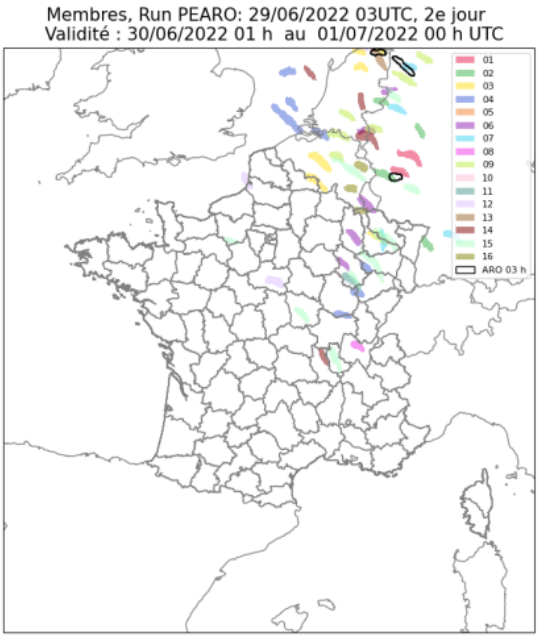

Figure 3.8.3. Bow echoes detected in the AROME-EPS members within a given time period, represented as a function of validity hour (one colour per hour, whatever the member). Courtesy by Arnaud Mounier et al. (Météo-France).

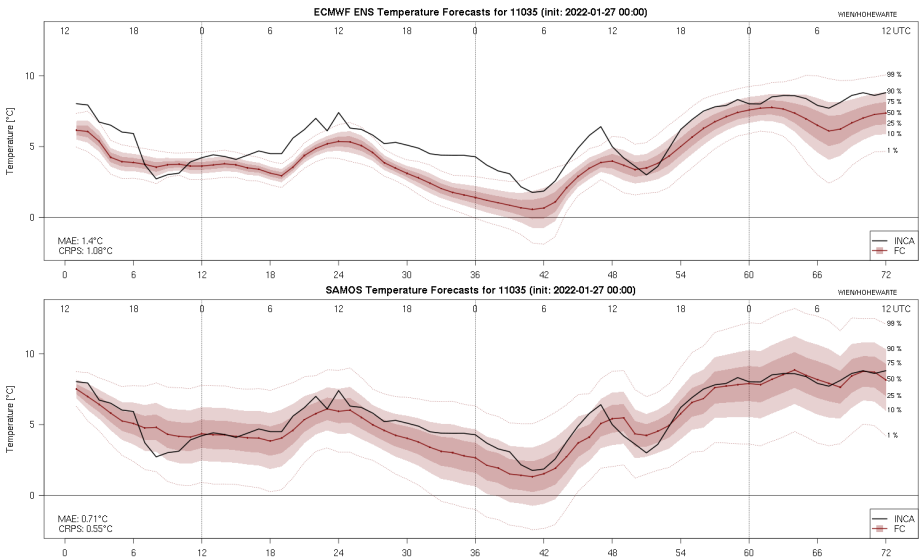

Figure 3.8.4. Comparison of direct model output (ECMWF-ENS, upper) and SAMOS (lower) for 2m temperature in Vienna for a test case. Black line shows observed temperature. Ensemble spread in SAMOS is much more realistic than in ECMWF-ENS. Courtesy by Markus Dabernig (ZAMG).

Using the URANIE VVUQ platform to study sensitivity of parameter perturbations
The feasibility of combining the URANIE VVUQ platform with HarmonEPS was investigated. Combining both scripting systems was done by abandoning the typical URANIE black-box approach and instead integrating the typical URANIE routines inside the HarmonEPS scripting system. First a sensitivity study of the T2m BIAS on the perturbation standard deviations of different surface variables was performed. This study identified the soil moisture perturbation standard deviation as most influential, confirming results from earlier studies and ensuring that the URANIE integration in HarmonEPS was done correctly. Next a calibration/optimization was performed. First the SPP pattern generator correlation length scale and T2m were identified as the optimal input–output combination through a sensitivity study. Finally, this input-output was used in a proof-of-concept optimization exercise using the URANIE EGO optimization algorithm. The outcome of the optimization exercise yields a sensible outcome in line with default HarmonEPS SPP settings, see Fig. 3.8.5.

The results of this deliverable show that the automated tuning of model parameters can be performed successfully via a combination of the URANIE tool from Commissariat de l'Energie Atomique (CEA) and a weather forecast model for full-grown ensemble prediction systems.

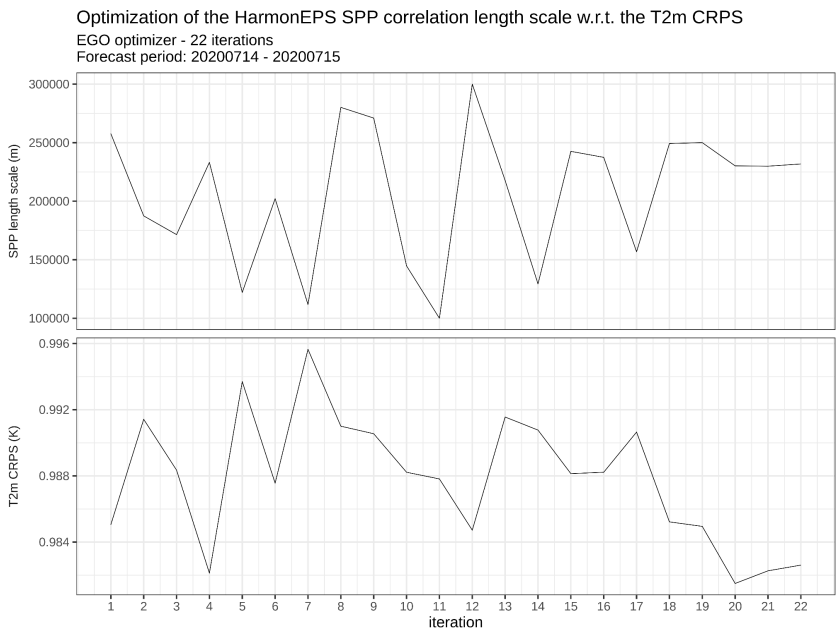

Figure 3.8.5. Evolution of L_{SPP} (top) and T2m CRPS (bottom) during the EGO optimization. The first 10 iterations represent the Latin Hypercube sampling. In the last 3 iterations we can see the convergence towards the optimal value. Courtesy by Michiel van Ginderachter (RMI).

- ***perspectives and priorities for 2023***
  - With an expected 30-40% increase in speed it is important that ensemble forecasts can take advantage of running in single precision. In particular, we need to confirm with certainty that none of the applied perturbations lead to numerical problems due to the reduced precision.
  - SPP has successfully been applied to critical upper-air physics parameters. Next year it is planned to test SPP for surface parameters.
  - The URANIE platform will be further tested on MUSC as a tool with which we can estimate for which parameters forecasts are most sensitive to perturbations.

- The use of AI provides a promising method for enhancing the number of ensemble members which is otherwise limited by the computational costs of running large ensembles (even in single precision). Next year we will work to widen research in this direction to more of the ACCORD consortium.

3.9. 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 assurance (WP MQA2)
  3. Quality assessment of new cycles and alleviation of model weaknesses (WP MQA3)

  MQA1 Development of harp

  The current ACCORD strategy identifies making the jointly developed harp verification system attractive as a common verification tool as the principal strategic goal of the efforts within the meteorological quality assurance area.

  This year has seen vigorous activity in supporting the use of harp. An on-line **training course** introducing the use of harp was arranged in February and attracted 75 registered participants (see section on highlights). The advantage of having a common interface providing simple, albeit limited control of harp functionalities has been recognized in the community. A first version of such an interface, the **accord verification scripts,** was constructed during a working week held in Helsinki on 7-10 June, based on software developed at Met Éireann and recent enhancements of harp. The scripts currently support point-based verification, and are capable of displaying many metrics and diagnostics in several ways not previously supported, such as vertical profiles, geographic maps, time sequences, scatterplots, or frequency histograms. Further details are given in the 3rd ACCORD Newsletter.

  Developments and refactoring of the harp code were presented at the 2022 ASW (Singleton, http://www.umr-cnrm.fr/accord/IMG/pdf/whatshappeninginharp.pdf). They include a unification of the treatment of point data and spatial data, that were previously stored as vectors or multi dimensional arrays, respectively, and treated in separate harp packages. In the refactored code, point data and spatial data can exist as columns in an R data frame, point data as a vector and spatial data as a list of 2d "geofields". Thus all data frame operations can be performed on spatial data, and many methods for point data now work for spatial data as well. Several **new features** are being implemented in harp, including new reading functions for observations and analyses, methods to extract vertical cross-sections or horizontal sub-grids, zooming in on a selected neighbourhood, upscaling of a grid by a user defined integer factor, and more. The link to the **OPLACE** database has been firmly established by adding code developments to the development branch of harp, and development is ongoing. An ACCORD scientific visit from ESTEA and SMHI to RMI in October is devoted to the use of **spatial verification** in harp. Topics of the stay include updating/upgrading of the main user interfaces, catering of coordinate systems, projections, file formats, and conversions needed to handle various satellite and radar data, and improved visualisation via the shiny server**.**

MQA2 Development of new verification methods

Quantifying the added value provided by increasing resolution of forecast systems continues to be a challenge, especially in the frame of ensemble forecasting. In an effort to overcome the well known double penalty effect hampering point wise verification, colleagues in France have continued deriving neighbourhood sensitive probabilistic measures. A generalization of the fraction Brier score /FBS) for ensemble forecasts by neighbourhood pooling and evaluating the Brier divergence for neighbourhood frequencies has been developed (Stein and Stoop, submitted to MWR, 44th EWGLAM). Using this metric and the ANTILOPE gridded precipitation analyses, the superiority of the high-resolution PEAROME ensemble PEARP has been demonstrated for precipitation forecasts over France.

Beside the purely mathematical quality measures, event-based evaluation has lately acquired more and more importance in Austria, and is used for operations and research alike, especially for assessing forecasts of extreme events. With the rising number of available model systems and the increasing update frequency it becomes more and more difficult to condense the available information into manageable form, and estimate the relative quality of available forecasts over areas and periods of interest. In order to overcome this difficulty, a "panelification" tool combining visualization of model results (panels) with verification metrics has been developed. The tool provides an overview of model performance and suggests a ranking of all models and/or runs. This type of verification started with precipitation, and is now being extended to parameters like lightning, hail and sunshine duration. This tool is intended to be used for quality assurance within DEODE.

Methods for utilizing new data sources, and making more efficient use of existing ones are important deliverables of the MQA area. Several new or unconventional data sources have been taken on board and used for forecast evaluation at various services:

- Short and wave irradiance from measuring stations are a valuable data source providing indirect information about aerosol loading and clouds, and have been used in Hungary and Spain and in Ireland. These data, however, may suffer from quality-issues and must be treated with care.
- Lightning strikes detected by the ATDnet have been used in Bulgaria for evaluating post-processed lightning probability forecasts from AROME-BG.
- Satellite imagery from MSG SEVIRI has been used in Morocco to assess the AROME-MAROC cy41t1 system, by inter-comparing observed and simulated images for channels WV6.2 and IR10.8.
- Mode-s wind data has been used for verification in the Netherlands. Mode-s provides valuable data at high resolution, but it is essential to upscale the data to the model grid resolution.
- Crowd sourced data from the CS-MASK project (Crowd Sourced data for atmospheric Modelling At Sub Kilometer scale) has been used in Belgium to evaluate hectometric scale Arome-runs. Thanks to the significant fraction of urban observations in the CS data, this project provides a unique opportunity to experiment with the TEB (Town Energy Balance) scheme that is used within SURFEX to model the town-atmosphere interactions.

An improved version of the HOOF tool for the homogenization of OPERA files (HOOF2) now implements additional functionalities for homogenization of data from different networks, dealiasing of radial wind data, and creation of super observations. The Python-based system is flexible and namelist-driven and now also includes a graphical user interface. (Smerkol, 2nd ACCORD N)

Significant progress has also been made in exploiting synergies between verification and data assimilation, as detailed in the section about highlights of the year.

MQA3 Meteorological quality assessment of new cycles and alleviation of model weaknesses

This work package 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 even the search for improvements. This latter activity typically spans over multiple ACCORD areas, and is often organized and reported in the context of model development, rather than quality assurance per se.

Verification of operational forecasts and evaluation of local implementations takes up the bulk of the reported work under MQA. Practices and reporting 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 used as well. Mainly point-wise metrics are used in routine verification, but spatial methods are being increasingly applied. The common verification software harp is being increasingly used for evaluating experimental configurations and e-suites. Operationally harp is used by the MetCoOp cooperation, in Ireland, and soon will be used in Slovenia.

Sharing of evaluation reports for operational and pre-operational suites within the community is strongly encouraged in the MQA-area. An encouragingly large number of teams have included such reports in their national presentations at the annual All Staff Worksop or the EWGLAM/SRNWP meeting. This year, lengthy evaluation reports for e-suites are provided by the French, Austrian and Spanish teams in the form of ACCORD Newsletter articles.

Case studies of derecho events, or widespread, long-lived, straight-line wind storms that are associated with fast-moving MCSs, have been reported by two teams. The Polish team (Kolonko et al., 2022, submitted) have analysed hind casts by ALARO and AROME for the derecho case in Poland on 11 August 2017. Severe weather phenomena, such as cold pool and rear inflow jet (RIJ), were predicted by both models. The Austrian Team (Weidle et al, 2022, EWGLAM/SRNWP national poster, Austria) analyse operational forecasts of thunderstorms with severe wind gusts of more than 140 km/h, that hit the south/east part of Austria 18.8.2022. AROME-Aut forecast from the 00 UTC run on the same day indicated wind gusts of more than 100km/h but poorly located. Most of the C-LAEF members confirmed the AROME-Aut forecasts with only a few members indicating high wind gusts on the right location. AROME-RUC forecasts indicated highest wind gusts in the right location but underestimated the wind speed at longer lead times. The latest AROME-RUC runs finally forecasted the event quite well, but too late to be used in operational forecasts/warnings. (This case has been added to the LACE database of cases)

Forecasts by A-LAEF of the record precipitation in Liguria region in Italy on 4/10/2021 have been analysed by the Slovakian team (Wastl, et al., 2 nd Accord newsletter, 152-165.) Several members of the operational A-LAEF system (coupled to cy47r2 ECMWF runs) predicted extremely high precipitation in this region. Coupling with cy47r3 ECMWF inputs was also tested, showing slight improvements. The A-LAEF EPS mean significantly outperformed the deterministic ALADIN/SHMU forecast concerning both position and amount of the severe rainfall. This case has been added to the LACE database of cases)

Underestimation of low stratus Austrian AROME-systems was investigated for the 11th March (Wittman et al, ACCORD 2nd ASW, National poster, Austra) . Removing all 2m observations (T2m,RH2m) from 3D-Var led to significant improvement. The problem could be also mitigated if the 2m values from CANARI were used as First Guess in 3D-Var instead

of the pre-CANARI values and if a different B-Matrix was used instead of the operational one (see also Fig.5). Finally, adding pseudo-RH observations from Austrian ceilometers could also significantly improve the forecast.

The Hungarian team has analysed two intensive convective events passed Hungary on 25 May 2022, with exceptionally large hailstones. (This case has been added to the LACE data base of cases)

- ***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.
  By contrast, the online harp training course and subsequent webinars that were arranged in February to March was a truly consortium wide event attracting more than 70 participants representing the majority of the membering countries. Other events arranged in the frame of ACCORD were the harp working week held as a hybrid event hosted by FMI in Helsinki, and the scientific visit from Estonia and Sweden to Belgium in October. devoted to work on harpSpatial.

- ***highlights from 2022***

  harp Training Course

  The 2nd harp on-line training course consisted of three days of lectures on 16-18 February, followed by several live coding sessions introducing workflows used in the real world, using real data with harp. The lectures, given by Andrew Singleton (Met Norway), Alex Deckmyn (RMI), and Mikko Partio (FMI), covered a brief introduction to R, the reading in of NWP data and harp data structures, point verification for both deterministic and ensemble forecasts, spatial verification of deterministic forecasts, statistical significance for verification scores, plotting forecast data, and an introduction to the construction and operation of an operational verification system (based on harp) within MetCoOp. These coding sessions included going through the verification of ensemble forecasts from start to finish, a case study of an extreme weather event, how to write functions that harp can use to ingest local data formats, how to build a package to adapt harp for local use, advanced plotting and more.
  The course material, including the recorded lectures, are available on the ACCORD wiki:
  https://opensource.umr-cnrm.fr/projects/accord/wiki/Harp_training_course_2022

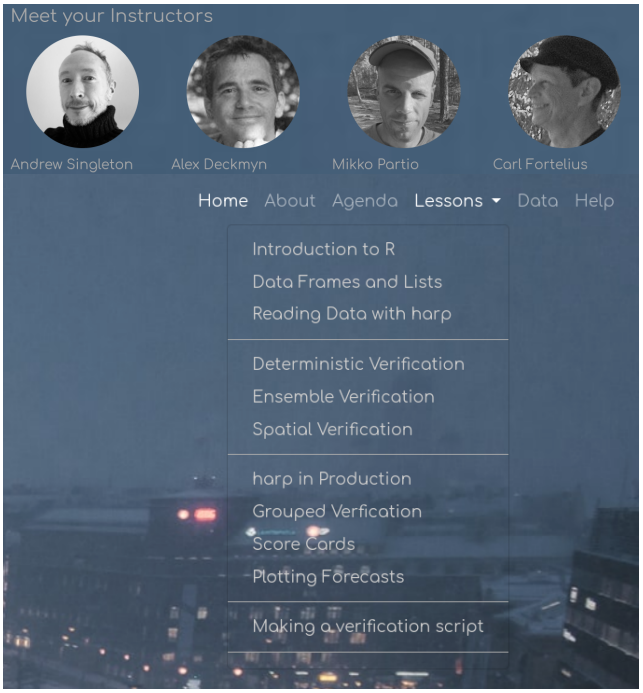

Figure 3.9.1 Instructors and lessons of the 2nd harp training course. Figure by Andrew Singleton, Met. Norway.

Exploiting synergies with data assimilation

In the context of data assimilation, much more data are typically used than in verification, and very advanced methods and software are used to compare simulated observations corresponding to a given model state (background) to actual ones. By replacing the background state with a forecast of arbitrary lead time, the same procedure can be applied for verification as well. Thereby it is possible to extend, with very little additional cost, enormously the amount of data that can be used. In France, prototype software was implemented under the name of SCOOPS, showing that the common code and OOPS can be used to generate metrics of forecast quality. In the frame of UWC-WEST a similar capability, based on ODB, has been developed. The teams engaged in this task will continue to work together.

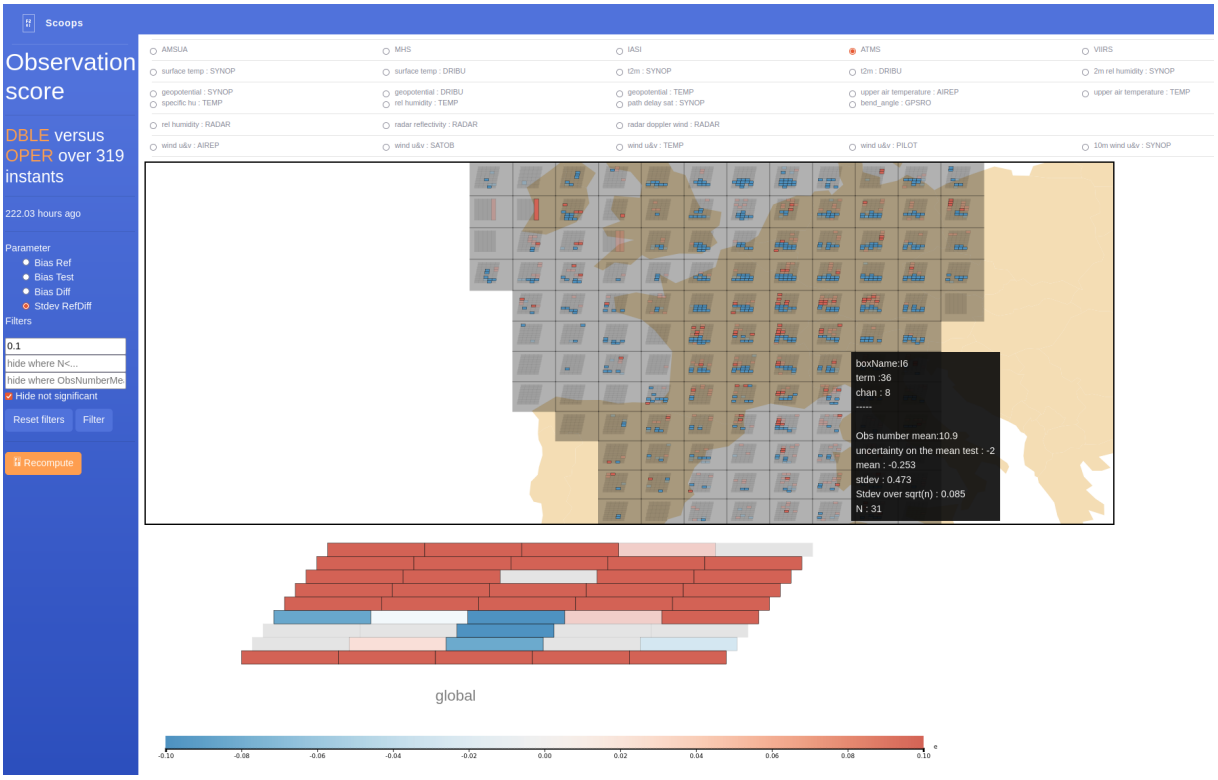

Figure 3.9.2 Capture from the SCOOPS user interface, showing the difference between two models in departure standard deviation for 9 ATMS channels displayed in rows for five different lead times (columns). Only significant differences are shown. Data for geographical regions are overlaid on a map, while a summary over the whole domain is displayed below. Figure by Florian Suzat, Météo-France.

- ***Perspectives and priorities for 2023***

The common user-friendly interface to harp still needs to be consolidated, enhanced, and improved. Identified topics for improvement include:

- documentation and guidance for first-time users
- generalizing the scripts for ensemble verification
- catering for spatial verification methods
- wrapper scripts to extract point forecasts from grib and FA format to be used by harp and/or written to sql database
- optimizing performance and ensuring full functionality of scorecard generation.
- ability to submit verification jobs via ecflow

The demand for data and methods supporting quality assurance of very high resolution forecasts and models will continue to grow, driven by needs of ACCORD members and by specific major endeavours in DEODE. Currently under-used observations supporting spatial verification, such as Mode-S, 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.

Meaningful evaluation of localized forecasts in complex environments such as built-up areas is a challenging area of research that will need much attention during the remainder of this MOU-period.

Regular verification and diagnosis of operational implementations and e-suites will continue as major activities in 2023. Findings, in combination with feedback from users, and findings

from case studies and field experiments inside and outside of ACCORD will provide guidance for further development of common codes. Collection and analysis of user feedback is currently organized individually by various members or groups of members sharing a common CSC, or acting together for other reasons, but procedures for ingesting user feedback at consortium level still remain to be defined and put to practice.

3.10. 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.

A major bottleneck for scalability in any NWP model is the need for I/O: e.g. to read initial and boundary data and to write forecast fields at required intervals. This can be done more efficiently by using an I/O server or by dedicating specific nodes to I/O, by asynchronous I/O, and by minimising I/O due to intermediate file format transformations.

It might be worth remembering in this 2022 reporting that some significant optimization effort was performed in 2020-2021. The coupling part of Arome had 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 had 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% for the cycle 48t1. These features now become available to all ACCORD partners who start installing CY48T1 in their local environments.

The Harmonie-Arome CSC has the capability to compile and execute the codes in single precision (SP), double precision (DP) and dual precision (2 binaries one single and other with double precision are compiled and at the same time, allowing use of them in a mixed precision simulation suite, i.e. the scripting allows to select which binary that is used in certain process in the model suite). The use of SP computations is currently explored for the operational EPS suites of some ACCORD partners. The RC-LACE group is working on enabling the radiation part of the ALARO physics for SP, with an aim to be able to call radiation in either DP or SP from either DP or SP core model. Eventually, the target is to run the ALARO-1b version in SP at least for A-LAEF purpose. MF is regularly assessing the validation of the AROME CSC in SP (actually mixed precision). It is envisaged in MF to implement mixed precision with the

next e-suite (CY48T1) for the EPS configurations (France, Overseas) as well as for the production forecast runs. If confirmed, this would mean that a significant fraction of the AROME forecast instances would be operated in mixed precision by 2023-2024 in MF.

The implementation of new more costly algorithmics in the modelling systems created the necessity to profile, analyse and optimise them for operational usage. This is the case of 4DVar data assimilation technique, that Harmonie-Arome has implemented as a feature in harmonie-43h2.2 version in April 2022 and also has been integrated in CY48T1 common code.

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 was released. The study made 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. All the project has been based on open source BSC tools. BSC provided way of using these tools with few manual interventions and also an online training to ACCORD system experts in the use of these tools for improving benchmarking and optimization procedures.[(2)]

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. For Harmonie-Arome a container allows to compile the code using GCC+OpenMPI and including ecFlow. In addition, the MUSC single column model has been containerized also, both of them for CentOS 8, and are available in https://github.com/Hirlam/HarmonieContainers.

The maintenance and development of the Harmonie Reference System (**SY2**) required a substantial effort from the HIRLAM System Group. During 2022, two versions of the Harmonie-Arome model have been released. The scientific version of harmonie-43h2.2 was released on April 25, 2022, which includes 4DVar and other important developments. For the first time, EPS testing has been included in the meteorological validation procedure.
A technical version, harmonie-43h2.2.1, was declared on July 19, 2022, including some fixes and the adaptations needed to run under new ECMWF's HPCF. As harmonie-43h2.2.x version will be used in operations a harmonie-43h2.2_bf is also available to establish a code feedback mechanism from O2R.
The new Harmonie-Arome release candidate will be based on CY46T1 and it is being developed as dev-CY46h1.This version has been regularly merged with the Harmonie cy43h2 codes to maintain the same level of development of cy43 both in scripts and 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. Some coordination with the ECMWF has been initiated to explore some common GRIB2 encoding for surface fields.

Since 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 using the pull request mechanism. In the process of maintaining code documentation as close as possible with each code version a migration of code documentation from the hirlam.org wiki to GitHub and it is accessible in https://hirlam.github.io/HarmonieSystemDocumentation/dev/. The cy43 will be the last cycle with documentation available in hirlam.org. Discussions between the HIRLAM System Team, the ACCORD SYS/AL and the ACCORD Integration Leader did take place in order to exchange experience and good practice when using the ***github.com*** environment for collaborative work on the codes.

Some training, in webinar format, on GitHub GUI and the new associated workflows took place using this https://github.com/Hirlam/PlayGround repository. Currently 71 forks of the playground repository have been created, given an idea of the interest and utility of this training action. Another webinar will be organized in 2022 to make more emphasis in the git command line solution.

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 and a preliminary under develop feature that will allow sub-hourly cycling.

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 dependencies, faster and parallel compilation, and better handling of code interfaces.

One of ACCORD's goals is to increase collaboration within partners. This has been described in three work packages **COM2.1** (Code generation and maintenance: regular maintenance and evolutions, official releases), **COM2.T** Code generation and maintenance: Transition to new work practices and environment and **SY4** (Towards a more common working environment: explore practical choices, prototyping, scripting). The COM activities will be described in more detail in the next section Organization of work within the consortium.

Thanks to the DEODE project a discussion about the minimum requirements and functionalities that common scripting and DEODE model engines has been initiated, and also some prototyping activities have been started. In the end of 2022, joint ACCORD/DEODE working days will be organised to progress in the search of synergies in the design phase of the model engines that can be reused for a common scripting in the ACCORD community.

(1) HARMONIE PERFORMANCE ANALYSIS: DELIVERABLE 2, BSC-CES-2021-001
HARMONIE, 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) Online training on Extrae and Paraver tools Barcelona Supercomputing Center – Centro Nacional de Supercomputación (BSC -CNS) for the study about the efficient use of the computational resources

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

  In the work package **COM2.1** (Code generation and maintenance: regular maintenance and evolutions, official releases), the progress on the coordination aspects and the work environment for planning timing and content of the code cycles, will allow to build a CY49 common cycle by the end of November 2022. Furthermore, in the follow-on of CY48T1 (whose build mostly spanned over part of 2021), two other T-cycle releases could be constructed, using partially the new working methods: CY48T2 declared on April 14 and CY48T3 on August 4.

  The technical validation of the codes is currently based on a set of unit tests implemented as a tool called 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 (ideally representative of canonical configurations including IFS, ARPEGE, AROME, ALARO, HARMONIE-AROME), automatic comparison of outputs to reference outputs, user-friendly display of these results. This validation is a crucial step in the process of integration and validation of code changes. That is why the maintenance of the test system, adapting test bench to CSCs evolutions, and introducing new tests has been performed. To facilitate this maintenance, 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. For this purpose a DAVAÏ contributors-developers Working Week will be organized in November 2022 and there are common computational resources thanks to an ECMWF's Special Project SPFRACCO dedicated to technical validation (testing) of contributions to a T cycle.

  A discussion about an important aspect like documentation has been started. Different levels of documentation have been defined and ways of organizing, maintaining and developing it will be discussed and proposed.

  Regarding coordination activities for the transition to new working practices (**COM2.T**) 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 in order to establish the starting point with the different partners in certain aspects related to the system. In order to know the level of local use of a Source Code Management tool (SCM), a questionnaire was 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 have been communicated to the ACCORD community in the 2nd ACCORD All Staff Workshop.

  The prototyping of an ACCORD forge[3] has been started on the GitHub platform: https://github.com/ACCORD-NWP. The prototype version has been opened to a small number of developers and system people. It is used to evaluate the working methods for code commits, Pull Request, management of documentation close to the code commits. The use of this forge is expected to grow with time, and a more systematic use of it during the construction of CY49T1 in the winter 2022-2023 is expected. This wider use comes with preparations of tutorials for the staff. The Integration Leader is the Prime Investigator of the source code forge solution, in close coordination with the System Area Leader and the team who has been

exploring GitHub for Hirlam. On a managerial and policy side, the MG (mostly PM with the IL and the SysAL) has been investigating whether the move to a cloud-based GIT solution would be problematic either in terms of code policy, or of financial requirements or in terms of manpower needed for its maintenance. As of today, no policy nor financial issue was noted (the current prototype is based on a free-plan solution). No additional manpower for the administration and the maintenance of the ACCORD forge itself seems necessary either. These needs will be continuously monitored by the MG.

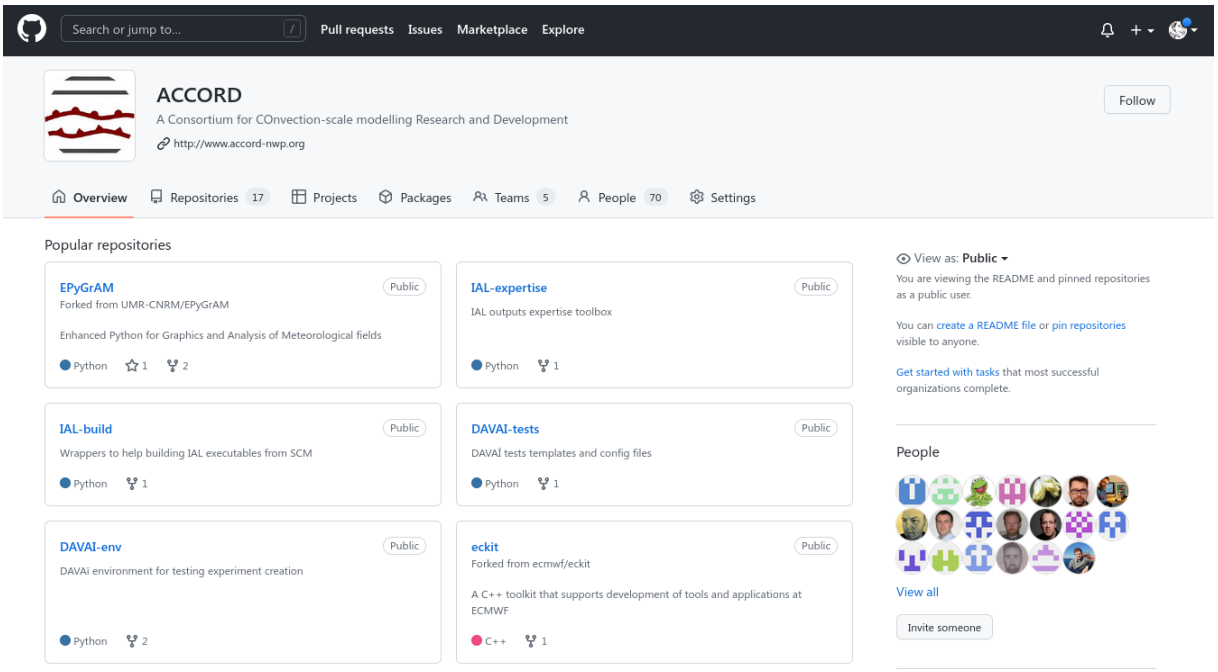

Figure 3.10.1. Entry page to the ACCORD source code forge under github.com. The forge itself can host several, specific GIT projects (which can themselves be with either private or public access). Designed by A. Mary, ACCORD/IL.

The exploratory phase for a common platform for exchange of information within ACCORD partners has been started. The goal is to have an ACCORD common platform where to host semi-permanent documentation, meeting notes and other material (e.g. web-links) that are relevant for scientific management. The assumed choice would be to go for some Wiki solution with an easy access and simple (yet secure) user/account management system.

(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.*

- ***highlights from 2022***

During 2022, there are several achievements that will help us to advance in the elaboration of more reliable and efficient NWP codes for use in the ACCORD Member Institutes. Reducing computational costs, through the use of simple precision computations, the implementation of new algorithms such as 4DVar and OOPS/EnVar, the prototyping of a more web-integrated SCM and a more portable DAVAÏ code testing tool, all are improvements that 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 2023***

The final choice of a solution for the ACCORD forge should be in place by the end of 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 CSC configurations, single precision computations and other compilation contexts like bundling tools and compilation systems. We would also like to kick-off the "DAVAÏ-contributors" team following the recommendations of STAC in June 2022. This will be a team of 4-5 system staff who will help maintaining the tests in DAVAÏ, under the responsibility of the IL and the SYS/AL. The effort is estimated to about 0.1 FTE/year/person.

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 although a proactive role with DEODE project might help in the possibility or reuse the model engine as modular components of a future common solution.

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

4.1. Evolution of the manpower since 2018 until end of June 2022

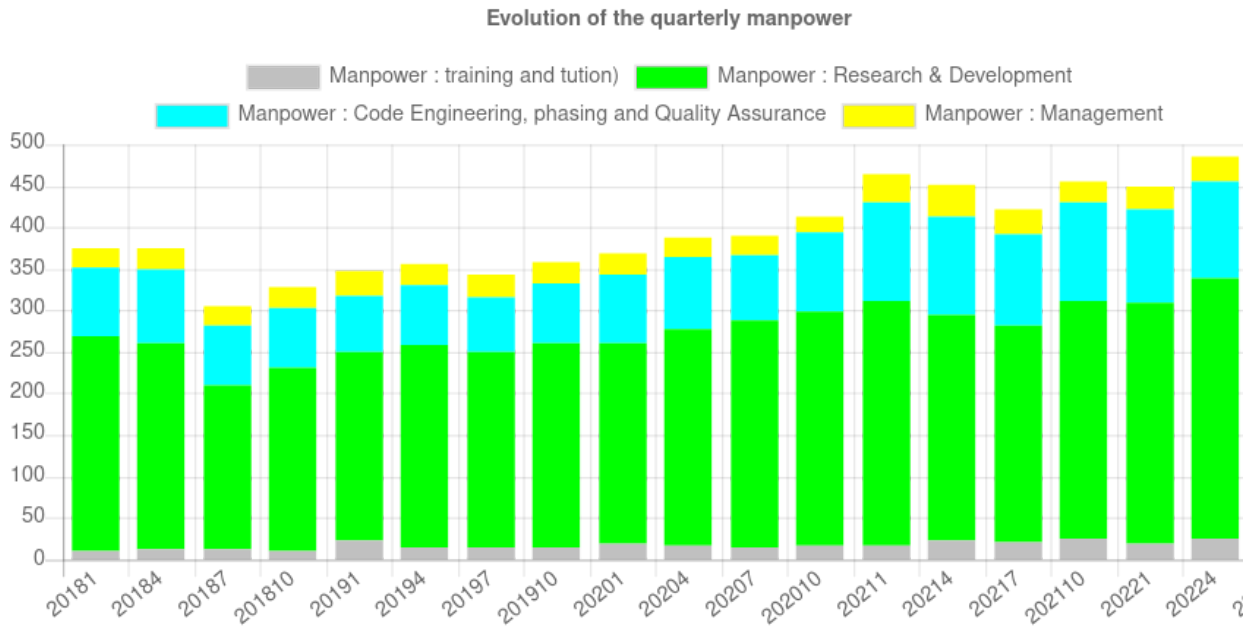

Figure 4.1.1. Evolution of the quarterly manpower dedicated to the Rolling Work Plans since 2018

4.2. RWP2022: commitments and realisation (first semester)

The final figures of the manpower realisation in 2022 will be published in the ACCORD RWP webpage in March 2023 after their checking by the MG.

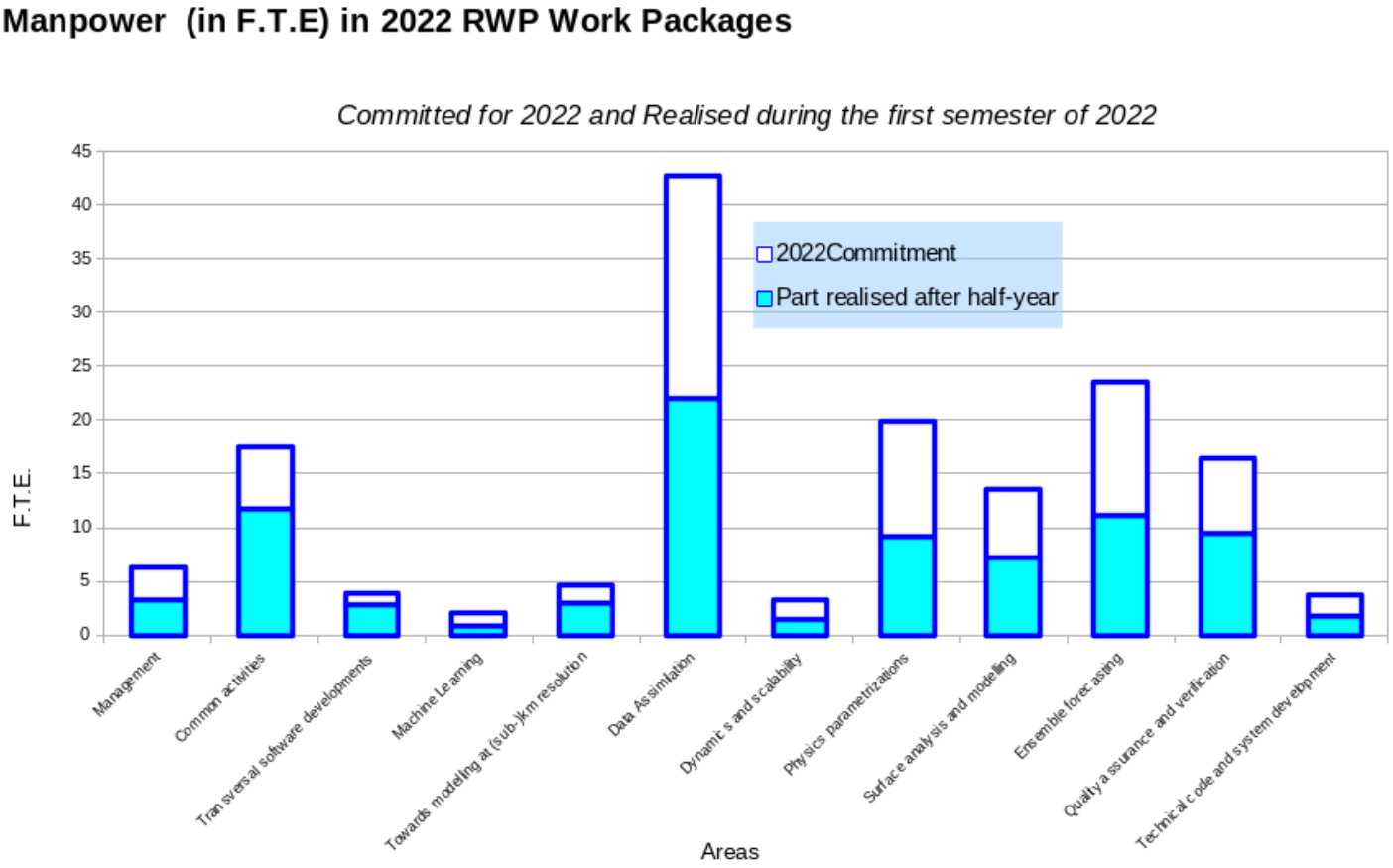

Figure 4.2.1. Commitments in the RWP2022 and work reported during the first half of 2022

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

Hereafter is a graphical overview of the recent and planned T-cycles and IFS-Arpege common cycles. Seen from the perspective of achievements in 2022, several aspects might be stressed:

- for both CY48T2 and CY48T3, the integration of code contributions partially did take place using the new work environment;
- a common GIT traceback history (aka GIT tree) has been implemented in CY49, for both IFS and MF-ACCORD codes (note: the GIT repos for IFS and MF-ACCORD will stay different, however tracking of changes should be largely facilitated with using a shared GIT tree);
- DAVAÏ testing has started on a more regular basis;

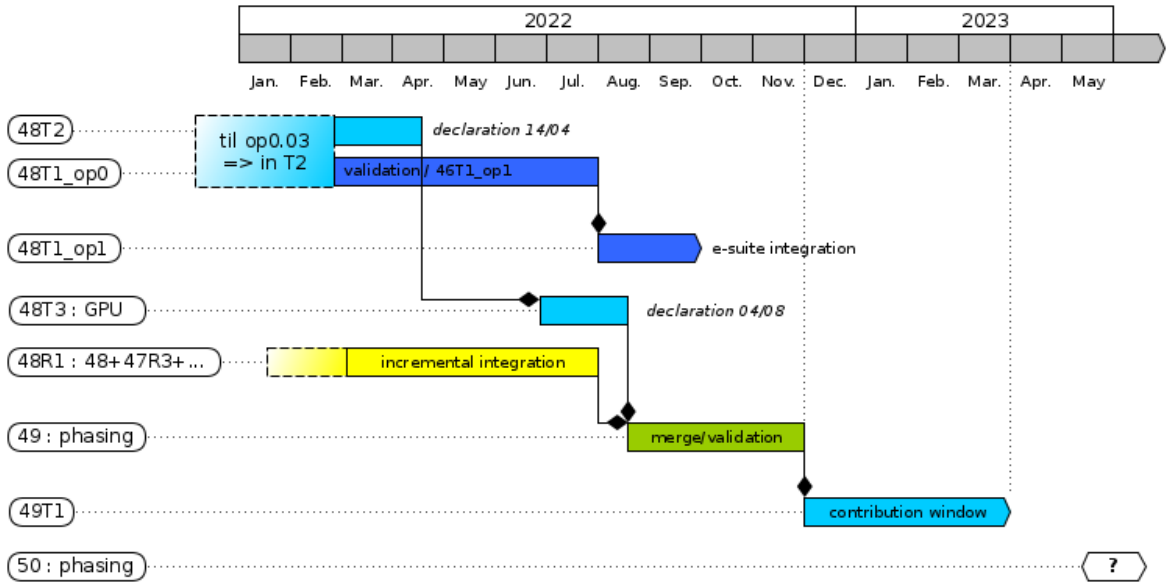

Figure 4.3.1. Overview of the recently built and upcoming T-cycle R&D releases, along with the main derived versions used by ACCORD partners

Hereafter a few additional comments on the graphics:

- 48T1: Last, most recent "open contributions" development cycle about R&D
- 48T2: Integration of several rephasing features of (pre-)oper developments + OOPS major upgrade (the contributions to this T-cycle were flagged)
- 48T3: Refactoring features in preparation for GPU-readiness / Bit-reproducible with 48T2
- 49: Merge of 48T3 and 48R1 - Convergence of MF & ECMWF Git trees
- 49T1: expected contents = various ACCORD developments, rephasing features from e-suites, common H+T version of SURFEX, pre-externalisation of PHYEX and FA/LFI, developments from ARPEGE-climate…
- 50: not planned yet, around summer 2023 ?