Execution of Rolling Work Plan 2024

ACCORD
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 ACCORD Management Group, as a companion document to the Rolling Work Plan for 2024 available here:

http://www.accord-nwp.org/IMG/pdf/rwp2024_adopted.pdf

2. Summary of ACCORD activities in 2024 on Management

2.1. Scientific Management and organization of the MG

2.1.1. Adaptation of the working procedure for the preparation of the Detailed Action Plans.

The ACCORD Detailed Action Plan (DAP) contains all actions funded by the budget, including the scientific visits and the Working Weeks/ Working Days organization and support to participants. In the first three years of ACCORD, the DAP had to be organized in the autumn and winter, and once a fairly stable version of the RWP for the same year was ready. In 2024, the timing of the preparation of the DAP scientific visits and WW/WD for 2025 has been aligned with the main steps of preparation of the RWP2025.

The discussions regarding the DAP actions (List 1) started soon after the preparation of the RWP2025 had started. The MG used the discussions with the teams for the RWP to also discuss proposals for DAP actions. In parallel, a form was made available for LTMs (and more generally to staff in coordination with their LTM) so that they could make proposals for the DAP as well.

In this reorganized process, the final decisions on the DAP remain in the hands of the MG. The biggest two differences are that (1) we offer the LTMs a formal possibility to make proposals (which MG members can then discuss with them), and (2) the DAP List 1 document could be ready soon after the Assembly has approved the budget of the next year (here 2025). Signing by the PM could occur in December, rather than February/March.

Below is a graphical representation of the reorganized procedure.

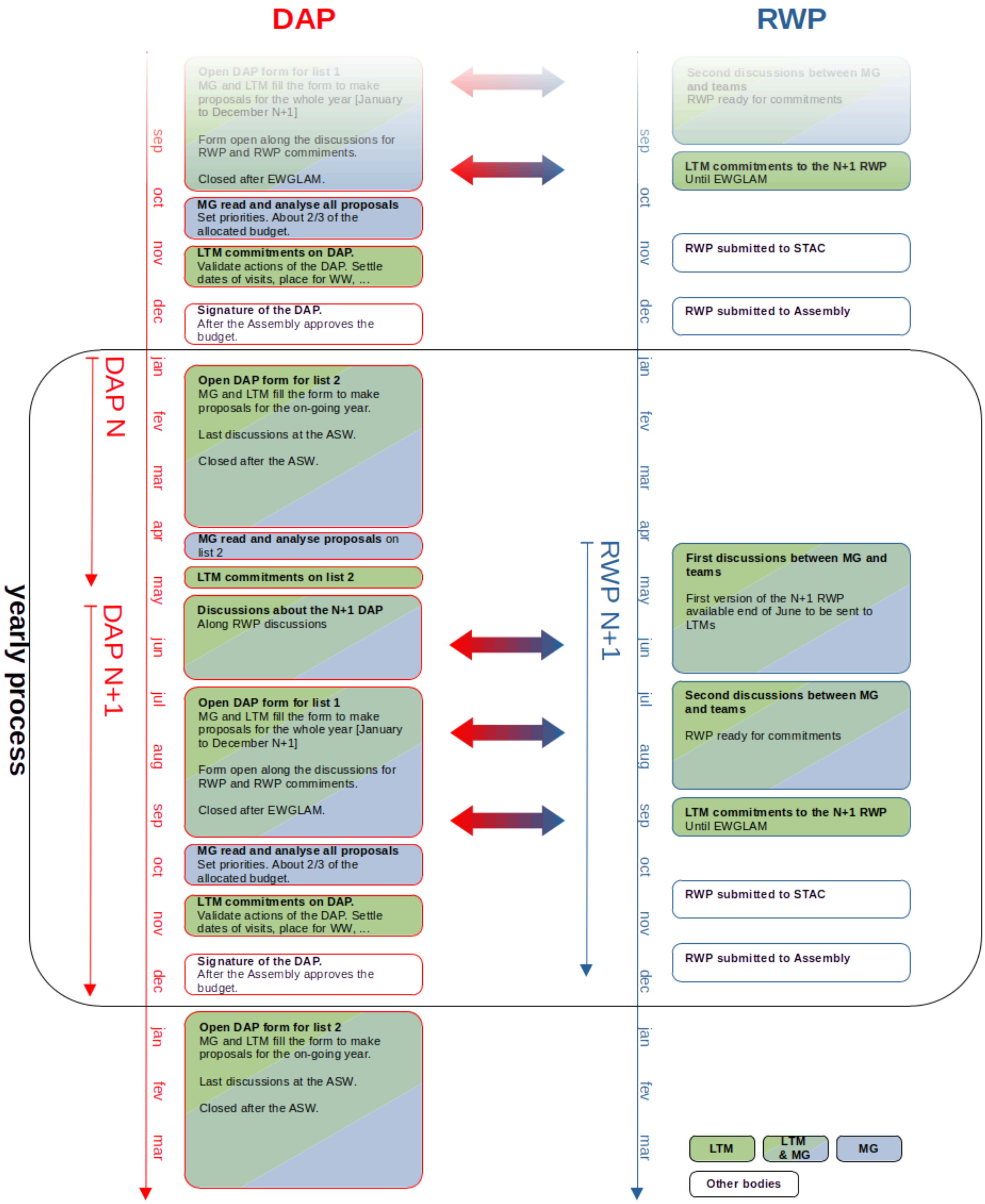


Figure 2.1.1: Graphical representation of the main steps of preparation of the DAP, aligned with those of the RWP. Courtesy by A.-L. Dhomps.

2.1.2. Preparation of the next phase ACCORD strategy.

The ACCORD MG has been heavily involved in the preparation of the draft scientific strategy proposal for the next ACCORD phase (2026-2030). MG members have been chairing (co-chairing) the Task Teams during the winter 2023-2024, and they played a very instrumental role in the Strategy Workshop held in Toulouse in May 2024. During the Workshop, the MG was complemented with a dozen of additional experts invited (some came in-person, others from remote). The outcome of the Strategy Workshop was a 30-page draft proposal submitted to STAC, who was proposed to review the document and make recommendations on both the form and the content. STAC therefore met in the beginning of June and then again in the beginning of September. During the summer, STAC members organized a comprehensive reviewing across their families.

The strategy drafting team, composed of the participants of the Workshop, worked on the revision of the strategy proposal in September-October, for a resubmission of the scientific strategy proposal to STAC in November.

During the STAC reviewing and discussion, the issue of the Common Scripting System (CSSy) emerged as the main topic with disagreement among the families, calling for specific additional consultation among STAC members in September (led by the chair of STAC and the PM). The outcome of this consultation process was the drafting of specific recommendations regarding the CSSy. Besides these recommendations for the drafting team, STAC recommended forming a dedicated task force to draw a roadmap for the implementation of the strategy on the CSSy. This particular action, *falling outside the scope* of the scientific strategy (which describes the main goals over the full time range until 2030) and of the drafting team, was endorsed by the ACCORD Bureau in order to address this sensitive and crucial item in a most agile manner. At the time of writing this report, the task force is being set up by the PM.

2.2. Information and communication

2.2.1. Documentation and Documentation Officer.

During the elaboration of the R2O white paper, the MG proposed definitions to help frame the effort on documentation. Five levels of documentation were established:

1. Scientific papers, Newsletter articles, Internal notes with scientific or technical description of a new feature, peer-reviewed papers.
2. User's guides, Tutorials, How To's.
3. Code related Documentation (close to the codes, close to the PRs).
4. Meteorological Validation
5. Reports of WW, Meetings and ACCORD Stays

The first set of concrete steps have been discussed this year, thanks to the official nomination of Jana Sanchez from AEMET as Documentation Officer:

- Make an inventory of each part of documentation. What do we have, where is it hosted and with what level of accessibility. Analyze which are the gaps and where the highest needs/priorities are.
    - Organizing documentation across the NWP collaboration and sharing a common referencing with ECMWF, Météo-France and the other ACCORD families (eg LACE, Hirlam/UWC)
- Investigate what the appropriate place for hosting the ACCORD Code Documentation could be. GitHub Wiki is one framework under investigation.
- Elaborate templates and guidelines for developers for documentation.
- Investigate what an appropriate tool for communication for ACCORD could be: general structure and divided by Teams, functionalities, prototyping.
    - ACCORD is currently setting up a frequent communication framework based on ***framateams***.
- Some reorganization of the ACCORD Web Pages and wiki (to adapt to new working practices on documentation) has started in collaboration between the Doc Officer and the MG members (for their Areas in the ACCORD wiki).

2.2.2. *Visits to member institutes.*

SMHI.

The ACCORD MG (AMG) used the opportunities of the ASW in Norrköping and of the EWGLAM conference in Prague, to meet respectively with staff at SMHI and CHMI.

The participants of the SMHI/AMG meeting included: Annika Thunell (Head of IT department, online), Fredrik Linde (Head of Division, Civil Protection), Eva Strandberg (Management and operational support), Heiner Körnich (Head of Unit Climate research), Bodil Aarhus Andrae (Head of Division, Management and Operational Support, Deputy Director-General), Jorge H. Amorim (Head of the meteorological research unit), Jelena Bojarova (group manager forecast and observations). The AMG on-site attendees were Patrick, Metodija, Claude, Alexandre, Carl, Martina, Daniel, Benedikt and Anne-Lise.

During this meeting, the SMHI management stressed the importance of validation and for the members to receive a well-tuned system. The scope of common codes was addressed and it was confirmed that scripts are included in this scope. The importance of showing the added value of our models with respect to global ones or to other numerical tools (nowcasting, AI) was emphasized. The link of ACCORD with Destination Earth (DE) was discussed and SMHI expressed their wish that this link be explained in the strategy. The meeting attendees agreed that still open questions remain such as for instance to what extent will DE impact the NHMSs. On the organisational side, the question was raised how to give the AMG the means so that they can more effectively steer the work in ACCORD. Another aspect was whether SMHI should nominate a User Representative given that model feedback already is organized at Metcoop and UWC level. The suggestion was that SMHI people discuss it further with Metcoop or UWC.

CHMI.

The AMG met the NWP R&D team of CHMI besides the EWGLAM/C-SRNWP conference in Prague in October. The meeting was in two main parts, the first hour was devoted to CHMI presenting the position of their institute in the institutional landscape of Czech Republic, and explaining the link of their NWP activity with users (in CHMI and external). The place of CHMI is extremely well recognized within the country. The institute is officially designated as the only authority mandated to issue weather-related warnings. It also benefits from national project funds such as "PERUN" in which CHMI is leading a partnership of 6 Czech institutes for implementing and exploiting regional climate runs on a dedicated HPC. CHMI furthermore is involved in Destination Earth DEODE.

The second half of the AMG/CHMI meeting was devoted to discussing R&D and the collaboration of the CHMI NWP group within ACCORD. CHMI explained that they highly rely on the R&D organization provided by RC-LACE which for them offers simpler means of coordination (because the LACE countries are geographically close and share a lot of common cultural and scientific background). A striking topic of discussion was the large impact of code refactoring on the work of the scientists. The CHMI team explained that understanding the new code versions was difficult for them, and updating their scientific options from an older to a newer code version was cumbersome because of the rapid evolution of the codes. The AMG took note of these difficulties, and pointed to a few directions for handling these issues (technical tutorials by experts on-site, check with other partners especially ECMWF and MF how they analyze these difficulties in their own scientific teams). The AMG however also pointed out that code refactoring was felt beneficial for the long-term maintenance of the codes, despite frustrating scientists in the short-term because of the steep learning curve.

The AMG agreed to further process with the other partners (ECMWF, MF) a set of questions relate to the impact of code refactoring:

- Will the ".FYPP" files continue to spread across the IAL codes ? They are felt as cumbersome to deal with when one has to implement a scientific contribution in the dynamics codes
- Is there any calendar of the main code refactoring features to still enter the IAL codes, cast across the timing of the upcoming IFS-Arpege cycles for instance ? (which could help anticipating the difficulties for phasing scientific contributions)
- Are there places in the IAL codes where code refactoring largely is completed ?
- Code refactoring is currently very intrusive in the IAL codes, how can we make the phasing of scientific contributions as little painful as possible for the developers ? How does ECMWF coordinate between the code adaptation team and the NWP scientists ? Is there any lesson to be learned for the wider community, or even any joint action of mitigation worthwhile to be considered ?
- What will the governance of code contributions and code evolution in the multi-repo context be ? Who will check and/or decide on the integration of code contributions in externalized repos ?

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

2.3.1. ECMWF.

The backbone of the ACCORD collaboration with ECMWF is the IFS/Arpege code collaboration, which entirely includes the code collaboration on the LAM components present in the IFS/Arpege codes. This entire coordinated code forms the core of the "IAL-codes". In the past 12 months, three IFS/Arpege coordination meetings have taken place with participation of the ACCORD/PM, the Integration Leader, the System and the SPTR (Code Refactoring and Adaptation) Area Leaders (November 2023, March and June 2024). The EPS AL joined one of the meetings where mixed precision for EPS applications was discussed. Another specific topic addressed in 2024 was the shared IAL coding norms, organized now in GITHUB.

In close relation to the IAL codes, some items might require dedicated attention by ACCORD in the coming months (2025): the continued efforts of code refactoring and their impact on scientific developments in the common codes, the coordination of code evolution in the multi-repo environment, the recent proposal by ECMWF to draft an IFS Software Strategy (first introduced in SAC-53), the continued trend of issuing a part of the IFS forecast model code under open source which is part of the ECMWF Strategy for the next few years (based on the perimeter of the OpenIFS code).

At the level of scientific exchange, ECMWF management and staff are systematically invited to join the sessions of interest at the All Staff Workshop (usually by remote participation). Many informal streams of scientific exchange exist (in the dynamics, on surface aspects, etc.). The scientific exchange with ECMWF also benefits from the Centre's participation in the EWGLAM/C-SRNWP annual conference (Prague in 2024).

2.3.2. Destination Earth.

Phase 2 of DEODE spans over 1/5/24 - 30/4/26. A main goal is to work toward the operationalization of the on-demand digital twin. The main links with the ACCORD work plans are via the installation and testing of new code releases (in DEODE: on EuroHPC machines), work on code adaptation, the further scientific improvements of hectometer-scale model configurations, EPS and uncertainty quantification. Several ACCORD teams also are active on studying data driven models. DEODE has started to develop its own scripting system, enabling it to run the 3 CSCs.

2.3.3. Cooperation with LEGMC (Latvia).

Following the signing of the ACCORD/LEGMC cooperation agreement in December 2023, valid for three years, the PM, the DA-AL and the MQA-AL have met with the team at LEGMC to discuss the 2024 activities (in spring) and the plans for 2025 (in September). Hereafter is a brief feedback from these meetings.

Status of work in 2024:

- remote participation in working weeks and workshops: ACCORD All Staff Workshop (6 participants), ‘harp’ training course (1 participant on site), DA-WW with a special focus on following the OBSMON online presentation.
- Development of a visualization front-end interface for ‘harp’, in Python (including collaboration in DEODE and with the ‘harp’ lead developers). This development will be registered in the contributions for the MQA4 work package in ACCORD.
- Coordination with the MetCoop group regarding the surface descriptions in the SURFEX databases.

It was noted that the LEGMC staff has a good expertise on Python programming and very little with R-programming. This technical background will shape the collaboration in the future and a focus will be on Python-based tools.

Planned tasks in 2025:

- Further development of the visualization front-end for ‘harp’; coordination with the ‘harp’ developer team (Met.no, AEMET).
- Gain knowledge on the DA-related verification making use of ‘harp’, get in touch with the developing team at Met Eireann. In parallel, discuss in the context of MetCoOp how the team at LEGMC could get involved in DA-related verification using the DA output of the MetCoOp Harmonie-Arome configuration.
- pending on staffing, further increase the involvement of LEGMC in DA in the MetCoop context and consider to gain knowledge on DA diagnostic tools. ACCORD could facilitate the transfer of knowledge of specific diagnostic tools toward LEGMC.
- Participation in ACCORD workshops and working weeks, usually remotely. If resources are available, an in-person participation to the All Staff Workshop and/or to a thematic WW will be considered.

3. Activity report per Area

3.1. Strategic program: Transversal software developments (SPTR)

3.1.1. overview of the activity in the area

In 2024, the activities in the SPTR work package are largely driven by two forces: the development of an ARPEGE benchmark running on GPU by MeteoFrance, and the porting of the ACCORD model to GPU-powered EuroHPC infrastructure in the framework of the DE330 project. This has led to significant progress in various aspects of the GPU porting of the ACCORD model. First, several parts of the code have been refactored in the sense that the data are encapsulated with smart data structures (FieldAPI library), and that the code supports a coarse (CPU-targeted) and fine (GPU-targeted) parallel granularity. For the ARPEGE global model, this work is finished for the gridpoint computations (physics and dynamics), the semi-Lagrangian interpolations and communications, and the semi-implicit spectral computations. For the ACCORD models, we largely benefit from this effort, as much of the code (especially the control layers) is shared with ARPEGE. As such, also the nonhydrostatic gridpoint dynamics, the LAM-specific parts of the semi-Lagrangian scheme and the ALARO physics have been refactored. Although the refactoring of the HARMONIE-AROME and AROME-MeteoFrance physics is more challenging, progress is made there, and the expectation is that this will be finished by the end of 2024. These developments will enter cycle 50t1.

An important side note on the refactoring were the concerns expressed by the CHMI team during a meeting with the ACCORD Management Group. As mentioned in section 2.2, some of these concerns regard the rapid evolution and significant changes to the Fortran code due to the refactoring, not only at the level of the control routines, but also in parts of the code (semi-implicit dynamics) where active scientific developments are going on. While both mentioned "driving forces" in the GPU porting come with a certain time pressure, it should be recognized that the fast progress in GPU porting at some level went at the expense of training, documentation and coordination with scientific developments.

Another important aspect of porting the ACCORD forecast model to GPUs, besides the refactoring of the model, concerns the actual offloading of computations to the GPUs. This is achieved through source-to-source translation tools. Again building further on the tools that were developed for ARPEGE, the creation of GPU code for the semi-Lagrangian scheme, the nonhydrostatic gridpoint dynamics and the ALARO physics through source-to-source translation is now ready. This means that we are now able to run all of the gridpoint computations, except for the lateral boundary conditions treatment, of the ALARO configuration on GPU. For the time being, these source-to-source tools are still done with Perl scripts using the fxtran Fortran parser, but these tools are being converted to ECMWF's loki framework.

For the porting of the limited-area spectral transforms, an effort was made to make a convergence with the latest developments of the global spectral transforms. First, the LAM transforms are now an integral part of the ectrans package (at least in the ACCORD repository, not yet in ECMWF's repository). Second, a GPU version of the LAM transforms was based on the so-called red-green branch of ectrans, which supports NVIDIA and AMD hardware. This version is highly optimized for both GPU architectures. Its use has been tested in the ACCORD model on the Leonardo EuroHPC machine.

Besides these main activities targeting the porting of the ACCORD model to GPUs, another approach is the use of a Domain-Specific Language (DSL) to achieve portable code. In collaboration with ECMWF and other partners, the ICE3 and the APLMPHYS microphysics schemes have been implemented inside the PMAP (formerly known as FVM) framework with the gt4py DSL.

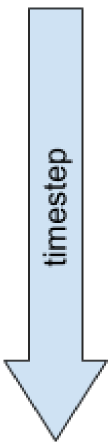
Finally, efforts were done to organize training and provide documentation for the activities in this work package. Two in-person trainings were organized within the DE330 framework (Helsinki

October 2023 and Toulouse June 2024), consisting of presentations as well as hands-on exercises. Also the ACCORD wiki page for this work package has received a serious update.

3.1.2. highlights from 2024

An impressive milestone that was reached in 2024 was the porting of a full time step of the ARPEGE global model to GPU. This achievement has made it possible to make fast progress with the porting of the ACCORD models. For the ALARO configuration, almost all of the gridpoint calculations can now be offloaded to GPU.

The following table gives an overview of the current status of refactoring and porting of the ACCORD forecast model.



	Refactoring	Porting to NVIDIA	Porting to AMD
IO	Not yet started	Not yet started	Not yet started
Inverse spectral transforms	not necessary; FieldAPI interface started	Done	Done
Gridpoint dynamics	Done	Done	To be tested
Semi-Lagrangian	Done	Done	To be tested
Physics	Done for ALARO; nearly finished for AROME and HARMONIE-AROME	Done for ALARO	To be tested for ALARO
Lateral boundary conditions	Started	Not yet started	Not yet started
Direct spectral transforms	not necessary; FieldAPI interface started	Done	Done
Helmholz solver	Not yet started	Not yet started	Not yet started

3.1.3. *perspectives and priorities for 2025*

- As it is expected that the refactoring of the AROME and HARMONIE-AROME physics will be completed by the end of 2024, the actual porting and offloading of these physics parameterizations can start.
- The refactoring and porting of the remaining parts of the ACCORD forecast model (LBC treatment, spectral computations) is also foreseen for 2025. As such, the aim should be to have a full time step of the 3 CSCs of the ACCORD forecast model running on GPU by the end of 2025.
- Start looking at the performance (time-to-solution and energy-to-solution) of the forecast model running on GPU.

3.2. Towards modelling at (sub-)km resolution (HR)

3.2.1. *highlights from 2024*

The ACCORD activity on VHR modelling and related R&D is now transferred to the topical sections (dynamics, physics, surface, DA, EPS and MQA). At this year's All Staff Workshop, several talks in the Applications session explicitly dealt with very high resolution configurations and use cases (DEODE seen from the digital twin implementation and proof of concept side, offshore wind forecasts, AROME-500m operational model version in Météo-France).

3.2.2. *perspectives and priorities for 2025*

The anticipation is that VHR R&D and exchange of information on specific VHR configurations will more and more be dealt with inside the thematic Areas of ACCORD.

3.3. Dynamics (DY1 to DY3)

3.3.1. *overview of the activity in the area*

Our primary goal is to provide a stable and accurate framework for the dynamics part of our ACCORD model. We benefit from a dynamical core that is highly efficient due to its semi-implicit and semi-Lagrangian scheme, allowing for very long timesteps. Although the time spent on spectral transforms remains a weakness of our model, it is still acceptable. The main challenge now is to achieve stable forecasts at hectometric resolution. Simulations at 500m grid spacing appear to be stable, with acceptable computational costs, and operational configurations at this resolution already exist. These efforts aim to enhance the performance of our current dynamics. In parallel, we are developing a new model, based on the Finite Volume Model (FVM), which is expected to be more stable and conservative, although potentially more expensive. We intend to compare these models (FVM and ACCORD) in terms of computational cost and forecast quality.

3.3.2. highlights from 2024

Design of vertical finite elements (VFE) scheme for NH version of the model : Here the main objective remains the same for years, to have a stable and robust vertical finite element discretization. Recently, constraints on levels A and B for stability have been removed and VFE have been made compatible with new dynamics options.

Semi-Lagrangian Horizontal Diffusion (SLHD) : The SLHD is a flexible tool to represent the numerical diffusion in the model, with the aim to better represent the cascade of energy at various scales simulating residual processes which are not well captured by other parameterizations. SLHD has an enormous number of tunable parameters and includes not only flow dependent grid-point diffusion, but also terms usually taken into account by spectral diffusion. Experiments at various resolutions down to 500m have been performed in order to tune and better understand the added value of SLHD.

Dynamic definition of the iterative time scheme : The idea is to use the iterative scheme that costs more but enables a more stable time step, only when necessary, when less stable conditions are detected in the model. The method enables the use of the ICI scheme (iterative method) with 2 iterations instead of the SETTLS scheme (classic extrapolation method) when necessary, saving some computational time. The instability criterion is based on the time derivative of the vertical divergence.

Experiments in very high resolution : Several experiments at very high resolution (up to 200m resolution) with nested domains were conducted, the results can be summarized as such : a) Smoothing orography gives better stability, cubic truncation of orography was used successfully with ALARO. b) The digital filter initialization helps to bring balance to the initial fields. c) The stability of integration depends strongly on the horizontal diffusion parameters used. d) In the context of ALARO, using SLHD helped handle the energy dissipation at refined scales. e). With properly set parameters, we may get stable integration with “standard setting” in dynamics.
Experiments comparing 750m linear grid with 500m quadratic showed no significant differences between those configurations.

Reformulation of the NH system as a departure from HPE : The aim of the topic is to reformulate the compressible nonhydrostatic system of equations as a departure from the hydrostatic system which may be controlled through several control parameters (all=1 : NH core, all=0 : HY core). Then all computations of the dynamical core can be treated in a unified code. Moreover, these control parameters can be vertically dependent. It would allow it to suppress nonhydrostatism close to the model top where the vertical resolution is too coarse to properly sample NH processes. This year the code modifications were ported to cy49 and the proposition of including partially the orography into the linear operator of the SI time scheme has been implemented and tested, showing an improvement in a 2D experiment.

New prognostic variables : A set of new dynamic options has been developed in recent years (new prognostic variable, new sponge layer, new implicit parameter for surface pressure, a more stable formulation for the vertical Laplacian operator of the semi-implicit). Tests have been performed in high orography situations.

Time-dependent semi-implicit parameters : It is now possible to modify certain semi-implicit parameters on the fly depending on stability needs. By taking half of the maximum temperature as the minimum for the semi-implicit, stability is ensured while maintaining good accuracy. Tests have shown improvements in unstable cases, particularly in the context of the DE_330 project. Tests were also conducted with the AROME 500m configuration, yielding promising results.

Future dynamical core : Work with the Finite Volume Module (FVM) model, developed at ECMWF in a local version has progressed : Test cases centered on the Alps have been established with the aim of using a realistic terrain with slopes and maximum altitudes that could pose challenges to AROME. A set of vertical levels closely reproducing the coefficients A and B of our operational configuration has been developed. The AROME physics has been largely transcribed into the GT4Py format. A recent version of the new FVM dynamic core developed at ECMWF has been retrieved.

Improvement of Semi-Lagrangian scheme : One research axis is the improvement of conservation and efficiency of our SL scheme. We aim to test the impact of conserving dry air (instead of humid air as done today). The optimal solution is to directly consider the equation for dry air conservation and define coefficients A and B relative to this new hydrostatic pressure, then use the mixing ratio as a prognostic variable.

3.3.3. perspectives and priorities for 2025

Very high resolution settings : Concerning the hectometric configurations, the testing will continue with the most recent cycles and options available. The consecutive model approach with nested configuration must also be tested since the resolution gap will be larger in the context of the DE_330 project.

SLHD : The work on optimal SLHD setting through TKE diagnostics will continue. The implementation of horizontal features into the turbulence scheme TOUCANS was already 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.

Time scheme on demand : We will continue the study with longer test period to see whether the stability of the scheme and the number of time steps where necessarily the PC scheme is used is really flow dependent (or meteorological situation dependent) or it is more or less constant for a given domain, time step and dynamics setting used.

Future Dynamical Core: Work on porting AROME microphysics to the FVM model will continue, with tests being conducted on both CPU and GPU architectures. One challenge is the integration of SURFEX; a solution involving as much automation as possible for porting and testing should be considered. Testing the FVM in an operational-like parallel mode and comparing its performance with ACCORD in terms of resource consumption and elapsed time is planned. Currently, the FVM requires very small timesteps, but this may be offset by its lower computational costs, especially on GPUs. Additionally, the possibility of implementing a discretization method that allows for larger timesteps should be explored.

Semi-Lagrangian Scheme: Improvements in the transport scheme will be a key area of research and development. Initially, we aim to activate options developed at ECMWF to enhance SL trajectory calculations. Furthermore, we intend to improve the conservativity of the SL scheme, with work planned on the COMAD option (option used to solve some semi-lagrangian failure to include outside air in a converging situation) to achieve this goal.

3.4. Data Assimilation (DA1 to DA9)

3.4.1. Overview of the activity in the area

During the first two quarters of 2024, a total of 187 person-months was dedicated to data assimilation (DA) work. To increase efficiency, the nine research and development (RD) teams, each corresponding to a DA package in the Rolling Work Plan (RWP), have continued to meet periodically. These meetings, particularly the three DA working weeks, proved valuable for fostering collaboration and knowledge exchange within the consortium, as indicated by a strong participation from a majority of ACCORD institutes. Members maintained a common reporting practice using a shared working document. In addition, regular bi-monthly meetings with the DAsKIT group have provided a platform for discussing and assisting in their implementation progress.

Algorithmic development efforts focused primarily on the integration of DA algorithms into the Object-Oriented Prediction System (OOPS) framework, with particular success in the implementation of 3D/4D ensemble variational (EnVar) assimilation which has allowed for operational implementation of 3DEnVar at Météo-France. Several HIRLAM members have worked on optimizing the 4D-Var configuration, with promising progress also being reported in its implementation in the OOPS environment. Efforts were also directed towards applying 3DVar in rapid-update cycles (RUC) for nowcasting applications. Finally, an effort was made to establish and maintain a repository of commonly used diagnostic tools (AccordDATools).

Advances in observation handling include the refined utilization of traditionally used observation types and the exploration of novel observation sources. The EnVar algorithm demonstrated notable synergy with various observation types, enabling flow-dependent, spatially inhomogeneous increments and improved feedback from observations through hydrometeors in the control vector. Enhanced coverage and quality of Mode-S data from the European Mode-S Aircraft Derived Data Centre (EMADDC) has triggered further work on preprocessing, such as new thinning approaches. Additionally, a new production stream named NIMBUS has been introduced to ensure a consistent supply of 3D radar data, with validation efforts coordinated by the ACCORD community. Direct assimilation of radar reflectivities into AROME-France's 3DEnVar system marks a notable achievement. Satellite radiance assimilation efforts are presented in a highlight section below.

3.4.2. Highlights from 2024

The following two achievements represent activities where current and past work has culminated in notable advancements:

➢ Implementation of 3D/4DEnVar in OOPS: The migration to OOPS DA codes enabled first operational implementation of 3DEnVar at Météo-France in 2024. Long-period impact studies have confirmed major positive impacts of 3DEnVar compared to 3D-Var, both for average scores for all parameters and over specific case studies such as high precipitation events, winter storms and fog. Recent studies of observation impact also demonstrated a better impact in an EnVar framework, for example for Mode-S observations, radar reflectivity, microwave radiances in the all-sky mode and dense crowd-sourced surface observations. While 3DEnVar substantially improves the spatial flow-dependency, its temporal extension, the 4DEnVar, allows for time-correlated background error and analysis increments, without the need for TL/AD models, as well as use of observations with higher, e.g. 15 minute frequency. First prototype at Météo-France (Brousseau, Vogt et al.) successfully overcame technical issues with adding increments at different times (4D IAU), and demonstrated positive impact on highly dynamic organized convective events such as a derecho case over Corsica.

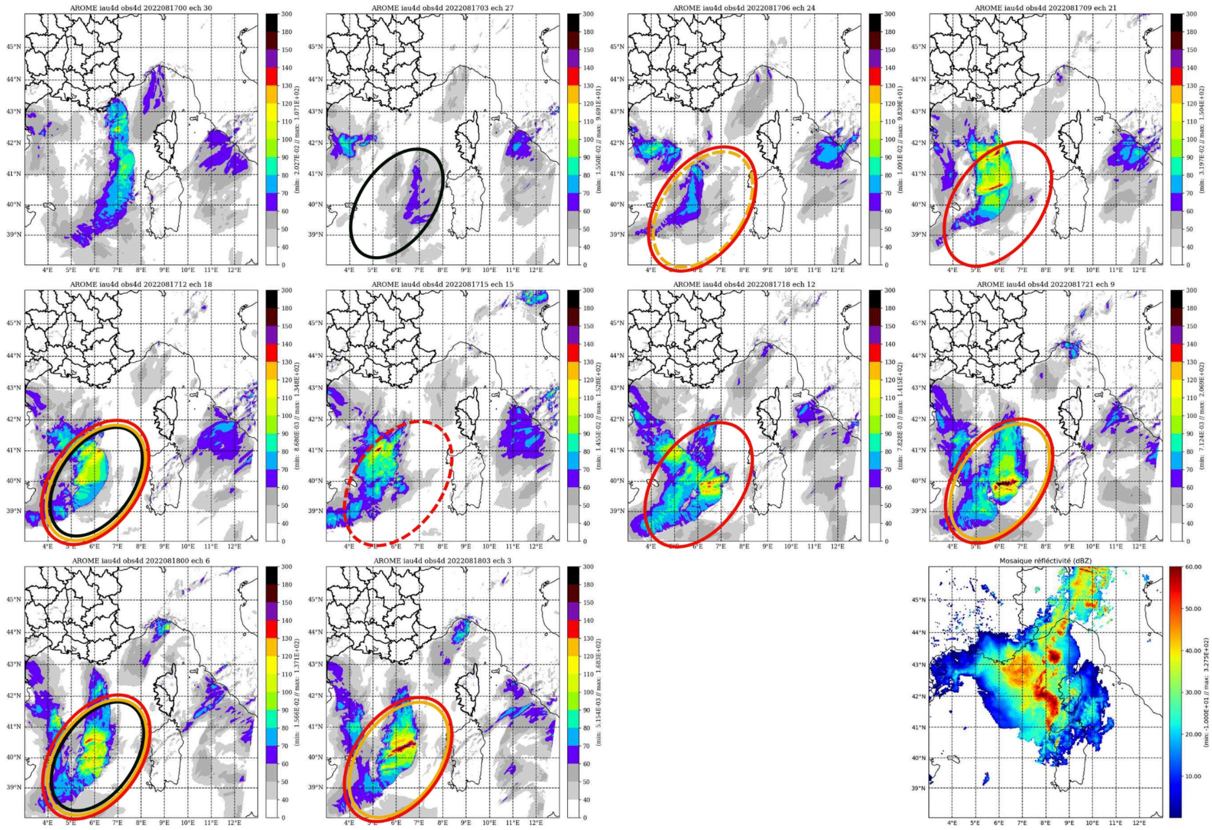
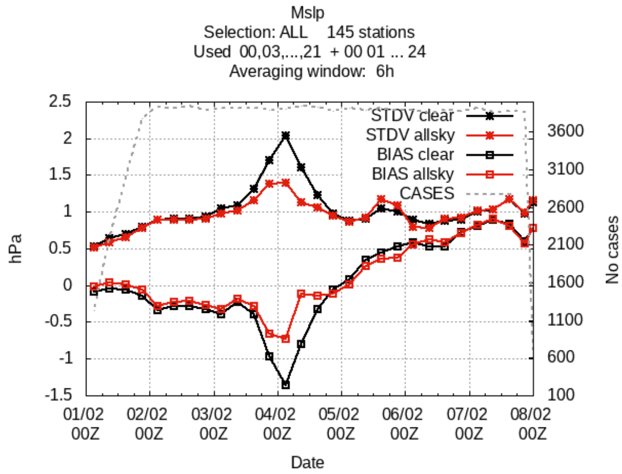


Figure 3.4.1: Wind gusts simulated by the different Arome-France 4DEnVar forecasts (from +30 to +3h in 3 h steps) valid at 2022-08-18 06 UTC and corresponding verifying radar image of the Derecho event on Corsica (bottom right). Red circles represent forecasts where wind speed exceeded the warning threshold of 110 km/h; the accompanying black and orange circles indicate presence of such information in the aligned 3DVar and 3DEnVar runs, respectively.

➢ <u>Improved radiance data assimilation:</u> Significant progress was achieved in the assimilation of satellite radiance data across several ACCORD centers. This includes the use of low-peaking microwave channels with dynamic emissivity estimation and improved Variational Bias Correction (Var-BC) for window channels (Guedj et al.), testing of different reflection models over ice and snow, the implementation of footprint operators for scatterometers and radiances (Mile), and especially the use of microwave radiances in all-sky mode (cloudy, rainy conditions). The research work was especially intensive at Météo-France (Chardon–Legrand, Borderies et al.) and included instruments GMI, AMSR2, MHS and MWHS2. The impacts obtained so far are positive and significant on clouds and precipitation forecasts (however one order of magnitude smaller than the change of ground radar assimilation method). However, it is expected that the impact will grow with more instruments converted from the clear sky to the all-sky route. Experiments in AROME-Arctic at MET Norway showcased the capability of all-sky assimilation in representing small-scale precipitation phenomena, such as polar lows (see figure). All these developments will also be applied to datasets from AWS, EPS-SG and possibly EPS-Sterna. Activities to assimilate IR radiances and sounder data in all sky-mode and visible channels kicked off and with a goal to enable an efficient use of datasets from EUMETSAT's MTG mission.



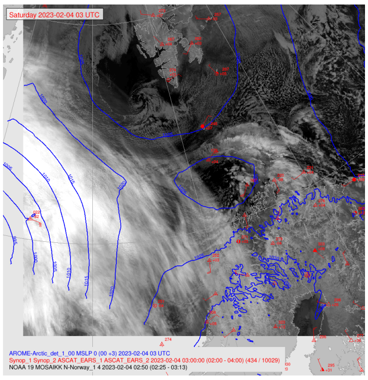


Figure 3.4.2: Verification of surface pressure during a polar low event north of Norway in the AROME-Arctic, comparing runs with clear-sky (black) and all-sky (red) MHS radiance assimilation. The all-sky run utilized 70% more MHS data and yielded a more accurate representation of the pressure drop associated with the moving weather system.

3.4.3. Perspectives and Priorities for 2025

Key priorities for 2025 include:

- Continued exploration of alternative observation sources (e.g., personal weather stations, smartphones) with an emphasis on improving quality control techniques (DA1),
- Further advancements in radar data assimilation, including direct reflectivity assimilation, wind dealiasing (DA2),
- Enhanced assimilation of satellite products, including all-sky radiances, low-peaking channels and lightning data, with ongoing improvements in bias correction and preparation for new satellite products (DA3),
- Continued development of 4D-EnVar to assimilate high-frequency observations at Météo-France, and experimentation with affordable solutions for the ensemble component of 3DEnVar by other ACCORD members (DA5/DA6),
- Finalization of the LAM 4D-Var implementation under OOPS (DA5),
- Exploration of DA methods suited for nowcasting applications (DA7/DA8),
- Ongoing development and dissemination of common diagnostic tools for monitoring and optimizing DA system performance (DA8),
- Exploration of machine learning applications in DA (DA9).

3.5. Physics parameterizations (PH1 to PH8)

3.5.1. Overview of the activity in the area

The ACCORD model physics activities in late 2023 and so far in 2024 were dominated by a few major aspects of the NWP system physics: activity towards 3D physics in NWP, activity towards a common single-column model (ACCORD-EMS), and activity towards enhancing the process-based evaluation. There are other important developments, e.g., wind farm parameterizations, that won't be reported here but on another occasion.

Towards 3D physics in NWP. Preparing our NWP systems to provide high spatiotemporal resolution weather forecasts on hectometric scales requires a more detailed investigation of the level of modification of the current parameterization schemes. Concerning the transport processes (PH1 and PH8), this includes studying the behavior of our turbulence and shallow convection schemes and their interaction with the dynamics solvers and the horizontal diffusion. More specific questions on this topic were discussed and documented during the workshop in Toulouse (MeteoFrance), organized by the ACCORD project (for MeteoFrance) and physics area leadership, and the attendance of experts from other consortia in place and remotely (DWD, SwisMet, ECMWF). The working question during the workshop was: what processes need to be included/restricted in the model physics when going towards higher resolutions and under which meteorological conditions? There, a clear strategy was established to investigate the open questions. This strategy includes a combination of observational campaigns and model setups with a common domain, outputs, and formats for validation. A follow-up of this activity resulted in the organization of an online session (p.10) half a year later. This activity is planned to continue in an additional online session in December 2024.

Towards a common single-column model (ACCORD-EMS). Maintaining, and upgrading a common single-column model (MUSC) framework is the main objective in the PH4 of the RWP2023/2024/2025. During the ACCORD working week at KNMI, the Environment for MUSC Simulations (EMS) was established (among users of all CSC within ACCORD) as a COMMON environment for future development. Porting and cloning the EMS and corresponding DEPHY software on the ACCORD-EMS GitHub environment was provided, along with installing and compiling HARMONIE system binaries within the EMS. This resulted in an efficient and robust use of the long list of predefined used case studies that could be automatically run for both AROME and HARMONIE cy46t/h1 namelists (currently, ALARO can use the forcing and initial files provided by EMS and run on its binaries outside EMS). The full integration (installation and compilation) of all CSC binaries within EMS is expected in cy49t1. Moreover, adding new idealized, but also realistic research cases in EMS is an ongoing process, and this activity is mainly done during ACCORD-EMS online working days.

Enhancing the process-based evaluation. The activity towards designing a more sophisticated process-based evaluation framework for our NWPs started in 2024. Much effort and time have been (and it is an ongoing work) put into discussions (scientific survey), planning and creating a common (ACCORD) infrastructure, gathering a variety of observational datasets, and software tools to establish a common working environment and more robust procedure when developing new or improving the existing parameterizations. This activity becomes even more actual when trying to show the added value of VHR simulation compared to coarser simulations or when comparing observation-based weather forecasts and physics-based weather (impact) forecasts. Due to its importance, this activity has taken an important position in the MQA goals of the ACCORD next-phase Strategy. However, developing and designing such a comprehensive framework currently relies on the developments in the Physics working groups (related to PH5, but not only). Thus a specific working week on process-based evaluation will take place in Madrid (EAMET) in November 2024. This kick-off action is expected to increase work efficiency by enabling researchers and developers to produce and compare scientifically based results.

3.5.2. Highlights for 2024 per CSC

In this section, several (among others) selected model-physics achievements during 2024 have been highlighted. By scientific category (working package, referring to the RWP2024), these achievements are reflected in developments and adaptations of the turbulence and shallow-convection schemes in high-resolution simulations (PH1), implementation of the ecRAD radiation scheme (PH2), developments of the single and double moment microphysics schemes (PH3), as well as replacing the TEGENS with CAMS aerosols climatology and investigating their impacts on cloud-aerosol-radiation (CAR) interaction (PH6). In what follows a little more detailed information is provided by ACCORD's Canonical System Configurations (CSCs), with additional references for deeper inside per subject (for mode interested readership).

➢ **AROME**

- Cloud-precipitation microphysics (PH3): Improvements in the negative bias of supercooled liquid water in ICE3 in cold areas have been shown in several case studies; further validation and comparisons with Harmonie-Arome (ICE-T scheme) and observations will continue. Improvements in the autoconversion consistency in ICE3 and the statistical cloud scheme have also been demonstrated. Increased flexibility usage of the second moment (LIMA) scheme has been introduced in PHYEX, as well as an introduction of two new secondary ice production mechanisms (droplet fragmentation during freezing and fragmentation during ice collision); more validation/tests are further required.

- Radiation (PH2): The integration of the new modular radiation ecRad scheme within ARPEGE, AROME, and MesoNH codes has been implemented, and tests with CAMS climatology have been shown. Both CAMS and ecRAD are already in operational use in AROME and ARPEGE. The ecRAD integrates the gas, aerosols, and cloud optics properties and allows consistent urban and forest canopy treatment. Moreover, the SPARTACUS solver in this scheme accounts for the sub-grid 3D radiative effects, thus opening a technical possibility to investigate these options for higher-resolution simulations. Evaluation, optimization of settings, and consistency with other parameterizations are still required. The possibility of using SPARTACUS on larger columns for 3D aspects in AROME is under consideration and planned for 2025.

- Turbulence and convection in VHR (PH1): Two available AROME setups use high horizontal grid mesh on 500 m: AROME-Paris and AROME-MedAlp. Preliminary tests of these setups over the Paris Olympics have shown mixed performance when compared to the operational AROME on a 1.2 km horizontal grid mesh; namely better performance of AROME-MedAlp for wind at 10 meters and temperature at 2 meters. The AROME-Paris setup simulations have shown inconclusive results concerning performance (mainly neutral). Overall, neutral performance has been shown for accumulated precipitation, but improved intensity of precipitation during extreme events has been demonstrated as well. The adaptation of the turbulence scheme to account for the small-scale horizontal turbulent transport has shown that more focus should be put on the appropriate modification of the vertical and horizontal mixing lengths (Fig. 3.5.1). Improvements in the shallow-convection scheme towards scale adaptiveness have shown encouraging results.

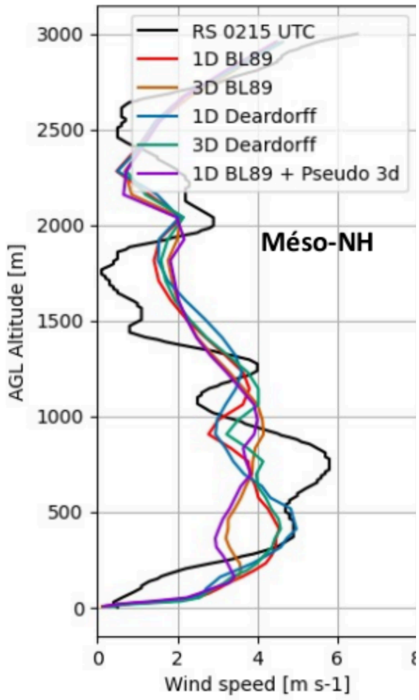


Figure 3.5.1 (Courtesy to Eric Bazile): Sensitivity experiments with AROME 200m including full- (orange) and pseudo- (magenta) 3D turbulence (shear-driven) effects compared to LES (MesoNH) similar setup using the BL89 TLS formulation, but also its replacement with the Deardorff TLS.

➢ **ALARO**

- Microphysics (PH3): Improvements in the single-moment microphysics schemes in ALARO to better account for the evaporation rates (Lopez-, instead of Kessler-based scheme) have shown a reduction of the precipitation bias in autumn and the frequency bias in summer indicating, for instance, better performance in capturing extreme precipitation. Work towards developing the double-moment scheme in ALARO has started and the preliminary results are encouraging for the double-moment rain and cloud water. Further tests with double-moment cloud ice, snow, and graupel are foreseen in 2025.

- Cloud-Aerosols-Radiation interaction (PH6): Available now is the possibility of using CAMS climatology instead of the currently used TEGEN aerosol climatology (Sekula et al. 2023), with the adaptation of their vertical distributions in ALARO (Sljivic and Masek, 2024). It has been shown that using the CAMS near-real-time (daily) aerosol provides an opportunity to increase forecast accuracy. However, it is currently computationally too expensive for an operational application.

- Turbulence and convection (PH1): There are mainly two upgrades in the TOUCANS turbulence scheme concerning modifications of the turbulence length scale (TLS, Fig. 3.5.2) and boundary-layer height (PBLH) diagnostics. An adapted and upgraded Rodier et al. (2017) TLS has been implemented in TOUCANS and has shown the potential to overcome the disadvantages of the Geleyn-Cedilnik TLS formulation (e.g., too sensitive to PBLH in statically stable conditions, underestimates daily and seasonal variability).

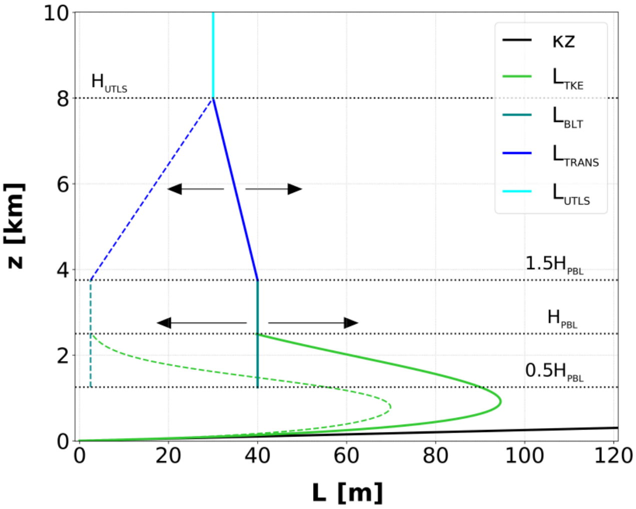


Figure 3.5.2 (Courtesy to Mario Hrastinski): A proposed and selected solution for the Turbulent Length scale (TLS) in the TOUCANS turbulent scheme in ALARO: L_{BLT} - regime-dependent near PBL top; L_{UTLS} - non-vanishing (constant) upper-air; L_{TRANS} - linear transition between L_{BLT} and L_{UTLS}; L_{TKE} - i) scaled with κ (L^{H24}) or ii) not-scaled with κ (L_*^{H24}).

➢ **HARMONIE-AROME**

○ A detailed summary of the research and development achievements in HARMONIE-AROME CY46 has been provided by Emily et al. (2024) in terms of a paper (technical note), which is currently under review (after revision) in Meteorology, MDPI (See pre-print before revision: https://www.preprints.org/manuscript/202407.1023/v1). Upgrades to the shallow-convection scheme (scale awareness, and option to switch off the moist convection updrafts and downdrafts after a threshold is reached in the vertical velocity), modification of the cloud-precipitation microphysics scheme (ICE3 to ICE-T, improving fog, low clouds, and visibility), and the use of NRT CAMS aerosols, followed by a set of tests and validations have been provided in the paper (and are expected to continue) along with other developments.

○ It is interesting to highlight the sensitivity and inability of different setups of HARMONIE-AROME in the regional 2.5 km HCLIM set-up to properly capture the observed mixed phase clouds via cloud liquid and ice water paths, (LWP and IWP, respectively) compared to data from the MOSAIC campaign (Fig. 3.5.3).

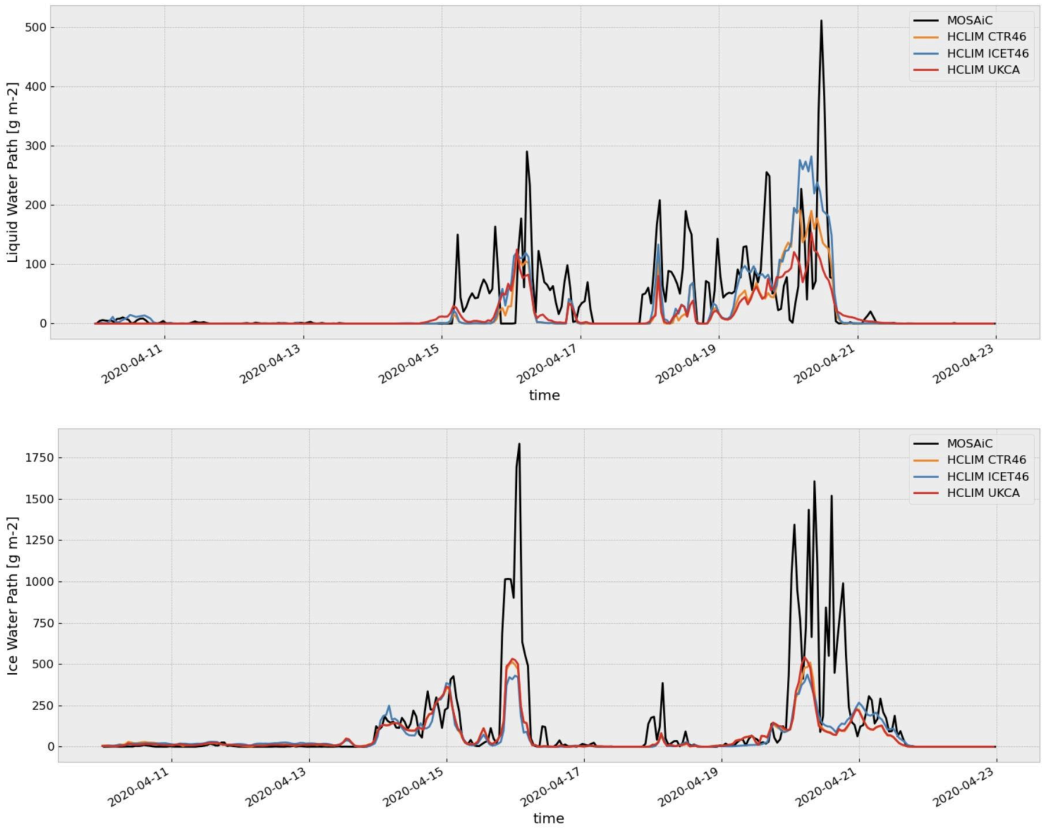


Figure 3.5.3 (Courtesy of Emily Gleeson, Oskar Landgren, Bjørg Jenny Engdahl and Filip Severin von der Lippe): Cloud liquid water (top) and ice (bottom) from three simulations with HARMONIE-AROME: cy46 control (ICE3) run (orange), cy46 with ICE-T, and cy46 CAMS-NRT setup, but with aerosol data from the UKCA model used as input (red line).

3.5.3. perspectives and priorities for 2025

The perspectives and priorities for 2025 for the ACCORD PH working group are stated in the RWP2025. However, some major challenges during 2024 remain unresolved and deserve special attention and mention here:

- Representation of very stable boundary layers and the consequence of a warm bias in the model (Fig. 3.5.4)
- Validation and process-oriented verification:
    - need PM commitments from several staff
    - use of gathered case studies (with obs) to evaluate key physics components separately and together (e.g. ICE-T, NRT CAMS, ecRad, LIMA, convection options, OCDN2)
    - start some inter-CSC comparison studies
    - use of DDH to understand what's happening in parametrizations
    - update documentation on model output and post-processing
- Implement a coarser grid for radiation
- Code refactoring work, get our developments into all cycles.

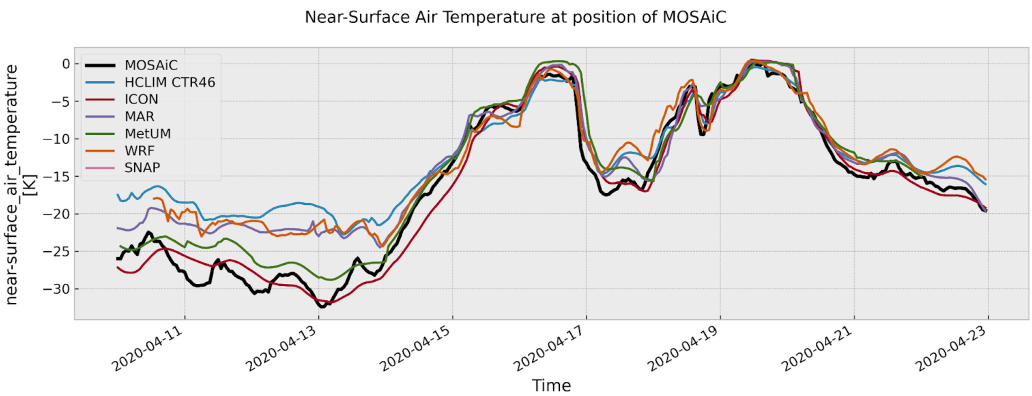


Figure 3.5.4 of (Courtesy Emily Gleeson, Oskar Landgren): Near-surface (2-metre) air temperature from MOSAiC observations at the Polarstern research vessel (moving with the ice). Model simulations are shown in different colours and observations in black.

3.6. Surface analysis and modelling (SU1 to SU6)

3.6.1. *Overview of the activity*

We have continued with the agreement among surface leaders to arrange one surface working week per semester at ACCORD level, the spring one in-person and the autumn one online only. Last November the online version gathered some 20 participants attending six different sessions (link to wiki). This year, in May, the in-person one was hosted by IMGW, Poland, and Gabriel Stachura where 8 people participated at site and some 15 by remote connection (link to wiki). The next online working week will happen November 25-29 2024 (link to wiki).

In addition to the ACCORD overall working weeks a specialised WW was arranged on TEB/urban aspects at KNMI, the Netherlands, in December (link to wiki) and an upcoming WW, in December in Brussels (link to wiki), will build upon the WW on multi-layer surface physics last October in Toulouse (link to wiki). The online monthly meetings have continued during the year (link to wiki).

An overall achievement started during 2024 to bring all our SURFEXv8.1 NWP developments as a contribution into SURFEXv9. This effort is built upon last year's achievement where we brought all our code into a common ACCORD SURFEX version. The SURFEXv9 work is tedious and hard since it involves solving of quite many conflicts and inconsistencies and very careful testing, e.g. by the use of the STRATO testing tool by the SURFEX team. The work is motivated mainly by two items: (i) to reduce maintenance and synchronisation of currently three separate SURFEX repositories and (ii) to bring our NWP SURFEX code to the level of the activities in the SURFEX team and therefore better utilise coordination work and further progress.

3.6.2. Highlights from 2024

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

surface model, physiography and data assimilation. In this section we present some specific progress in these topics during the last year.

Surface model:

The Force Restore and D95 snow combination for the nature tile is still the working horse in all operational NWP setups. However, we see more and more activities connected to multi-layer surface physics setups, within ACCORD itself but also connected to external projects like e.g. Deode and CARRA2. A cross-family team is working on improvements of the multi-layer surface physics, lately with focus on performance related to agricultural areas w.r.t. the surface energy- and water balances. Now and then problems in screen level variables are reported where the sources of the problems are not easy to identify since they often involve both physiography, model and assimilation issues. Lately the realism of ECOCLIMAP Second Generation (ECOSG) has been questioned in this respect but it can also be so that the issue is how the physiographic information is interpreted by the model. These aspects are now looked into.

Many operational setups have TEB activated for the urban tile of their domains, but not all. When TEB is activated it is represented by its most simplified options, which still means quite an advanced urban process scheme. Examples have been given where TEB parameters are shown to have questionable values and therefore give less favourable results, like e.g. for the urban heat island effect. Presentations are given with such examples but one difficult aspect to achieve is to bring such presented experiences into more operational setups. Here our efforts to share namelists settings among ACCORD partners in an organised manner will help. Fascinating efforts are currently performed beyond the classical TEB setup in SURFEX, namely the efforts to bring skyscrapers into the atmospheric part of the system, more concretely to let energy exchange happen between tall buildings and model levels. This work is made possible by the SURFEXv9 efforts described above.

Last March a sea- and ocean coordination meeting was arranged where colleagues in ACCORD countries were invited to share their research and developments related to NWP and climate activities for coupled atmosphere-ocean modelling. At Météo-France NEMO activities are ongoing directed towards both climate and NWP modelling while in HIRLAM countries the NEMO activities mostly involve HARMONIE-Climate (HCLIM) colleagues. Most of these activities are related to projects outside ACCORD and therefore any deeper ACCORD coordinations are currently not on the agenda. At Météo-France development and testing of the SURFEX 1D Ocean Mixing Layer (OML) for Arpege has approached well and it is very probable that the OML will be activated in the next global Arpege setup, cy49. Not enough time yet to validate it in LAM Arome-France configurations. Figure 3.6.1 by Adrien Napoly (Météo-France) shows that activation of OML improves results in the North Atlantic.

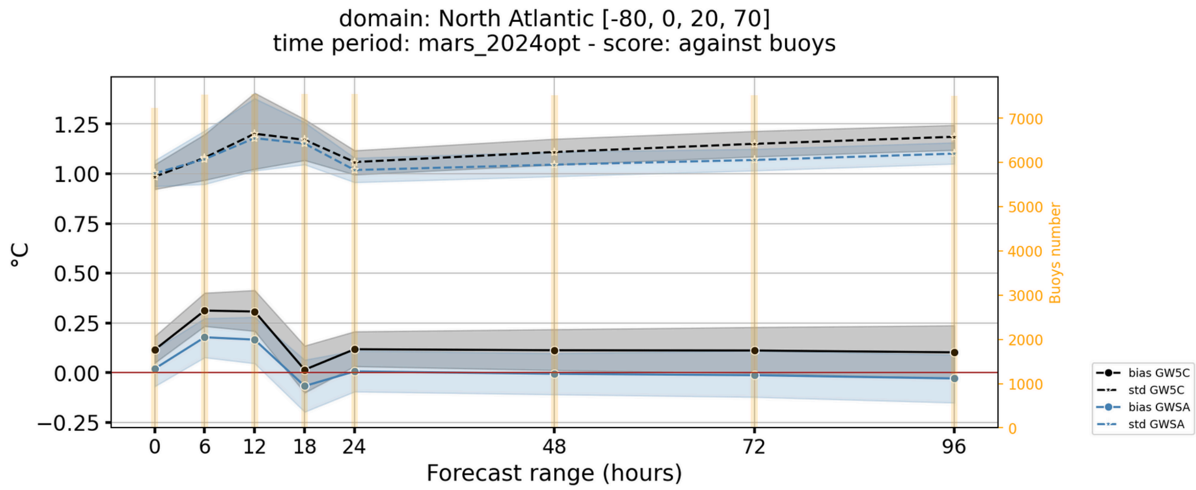


Figure 3.6.1: Bias (solid) and STD (dashed) of OML SST against buoys in the North Atlantic during March 2024. GW5C (black) means constant SST based on Mercator+buoys and GWSA (blue) means with OML prognostic SST.

The inland water part of the surface is also treated differently in our operational NWP setups. Very simplified solutions are around which might be defended by the low percentage of inland water in some of the domains. However, the lake model FLake provides a more robust treatment of lakes and it has been actively used by many northern Europe partners where a higher percentage of inland waters is present. Testing and application of FLake is ongoing activity for a few operational domains still omitting it.

In LACE the work on SURFEX for the ALARO-CSC has gone from debugging only to testing and development. A contribution was made to cy49t and the common ACCORD SURFEX version. Testing will continue and further development needs will be identified and worked on.

In connection to CARRA2 Arctic reanalysis developments, an effort was made to tackle a warm T2m winter bias for the stable surface layer, identified over eastern Siberia. Unfortunately the efforts never led to any substantial improvement so together with atmospheric physics colleagues this issue is still on our agenda, although no one is really surprised about that.

Physiography:

Operationally in ACCORD the land-cover is based on ECOCLIMAP 1st (ECOFG at 1 km) or 2nd (ECOSG at 300 m based on ESA-CCI land cover) generations depending on setup. Also other physiographic databases vary in use, e.g. with respect to soil texture and orography. A more homogeneous setup environment might be able to achieve, again coupled to the efforts of documentation of namelists, where also recommended settings can be discussed and listed.

Work on alternative land-cover databases are ongoing for a couple of reasons: To overcome the issues with ESA-CCI land cover as already reported (e.g. too homogeneous and not representative) and the need for even higher resolution O(50-100 m). Since last year, two different Machine Learning (ML) methods based on the agreement-based reference map building (ECOSG+) and the map translation approach (ECOSG-ML) have been released. These are applied to generate ML-based physiography at 60 m resolution from a multitude of input data. The methods are documented and published by Geoffrey Bessardon et al. (2024) and Thomas Rieutord et al. (2024). Work now continues at FMI by Rudolf Mård and Panu Maalampi.

Data assimilation:

For operations the combination of 2D-analysis of SYNOP observations with CANARI and vertical OI assimilation in the SODA/ASSIM part of SURFEX of soil temperature and soil moisture is still dominating. Only one exception exists and that is the Hungarian Met service which applies SEKF for the vertical assimilation. It should also be mentioned that a few Met services are not yet applying any surface data assimilation but development is ongoing.

Thus, from an operations perspective the surface data assimilation looks very homogeneous in ACCORD. However, for research and development, to reach next generations of operational setups, we have quite a wide spread in both algorithms and use of observations. One reason for this is that some major activities are supported by external projects.

For the 2D analysis part CANARI is being complemented with the Pysurfex package developed at MetNorway and by the 2DEnVar system developed at Méteó-France. Compared to CANARI, Pysurfex represents a totally stand-alone open source package in modern python code which includes the quality-control package titanlib and the 2D-analysis tool gridpp. It is also developed for an efficient use of crowd-source observation like Netatmo. The development of the 2DEnVar system is being done within the OOPS framework and has the intention to direct us towards a less weakly coupled surface-atmosphere data assimilation system.

For the vertical assimilation part, beyond OI and SEKF, we have activities mainly based on different flavours of EnKF. During the last year, in connection to the CERISE project, we have seen development and results for the Ensemble Square Root Filter (EnSRF) and the Local Ensemble Transform Kalman Filter (LETKF). As the names indicate, these methods are attractive for ensemble-based NWP systems.

At MetNorway an additional method has been developed to reach realistic initial values for the soil. It is based on running SURFEX offline continuously for a long time, forced by as good forcing as possible which means e.g. analysed precipitation, temperature and humidity fields. This creates soil-state variables well in balance with observed weather and which are then used as initial values for the surface part of the coupled system. This method will be further developed for the Deode system.

On the observation side, beyond SYNOP observations, we currently have activities which include products for satellite based surface temperature, soil moisture and snow but also assimilation of radiances via observation operators. For the observation operators we see interesting applications based on Machine Learning methods.

3.6.3. *Perspectives for 2025*

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

Surface model:

We see now more activities to take next steps towards a more time evolving sea-surface temperature (SST) in the forecast step of our NWP models. It is foreseen that these activities will continue to evolve over some time.

The efforts towards a robust multi-layer setup for the land-surface part will continue and concrete activities are on the agenda, e.g. with respect to improved surface energy- and water balance processes for agricultural areas.

The LACE community has invested greatly in identifying and solving identified issues with SURFEX from an ALARO perspective, which also benefits others in the ACCORD community. These efforts will continue in an ACCORD collaborative manner.

It is argued that the development we see in TEB-atmosphere coupling should be extended towards tall vegetation (forest). Discussions in this direction will start but the time frame and research investments needed are still quite unclear.

Physiography:

As the horizontal resolution of our NWP systems is increasing we also need to support this strive with relevant physiographic information. This is done by replacing ECOFG at 1 km resolution with ECOSG at 300 m resolution and to continue to develop the next step, ECOSG+ and ECOSG-ML at 60 m resolution. Another challenge, not really started yet, is to also complement these higher resolutions with high-quality parameter data including Leaf-Area Index and albedo.

Data assimilation:

The activities described above are medium-long term in the sense that they will continue into 2025 and partly onwards as well, since some of the activities are connected to external projects and their deliverables. The longer term goal expressed is to go for a less weakly coupled surface-atmosphere data assimilation system within the OOPS framework where the assimilation system is not really separated into atmosphere and surface as today.

3.7. Ensemble forecasting and predictability (E6 to E12)

3.7.1. *overview of the activity in the area*

The work in Ensemble forecasting and predictability is split in three categories: Perturbations (E9-E12), migration and preparation/upgrading (E8) and post-processing (E6-E7). The committed person months to the area in total has been approximately 20% less in 2024 than in 2023, but close to the total commitment for 2022. Some of the reason for the reduced commitment for 2024 is probably that resources have been moved to new areas such as DEODE and several of the European and national initiatives in machine learning.

Perturbations. Work has continued on parameter perturbations, either stochastically perturbed throughout the forecast (SPP; LACE and HIRLAM) or randomly perturbed at the beginning of the forecast (RPP; Meteo-France).

Migration and preparation of ensemble systems. Compared to last year there has been less effort on migration, probably because last year several teams were still struggling with migration to ECMWF's Atos hpc, while this year both C-LAEF and A-LAEF have been upgraded, and the e-suites based on cy46t1 are expected to become operational in 2025.

Post-processing. Post-processing includes both ensemble calibration and development of products targeted at users. AI/ML methods are increasingly being used for post-processing and are expected to replace more traditional, simpler statistical methods and methods based on analogs.

Working weeks. A working week was held at HungaroMet in January 2024 with 14 in-situ participants, see https://opensource.umr-cnrm.fr/projects/accord/wiki/Budapest_22-26_January_2024. Presentations and work included development of SPP for several new parameters, methods for testing parameter perturbation sensitivity, including use of the URANIE framework; and ensemble post-processing targeted at the renewable energy sector.

A second working week will be held at FMI at the end of November.

Scientific visits since last reporting include a visit from Met Éireann to RMI with the purpose to include URANIE in the HARMONIE-AROME workflow (see presentation by Michiel van Ginderachter, RMI), and two visits to GeoSphere Austria, one from DHMZ during which flow-dependent SPP was further developed in C-LAEF, and one from SMHI during which (i) SPP was implemented in cy49t2 in a version that can run in both AROME and HARMONIE-AROME and (ii) the flow-dependent SPP was ported to HARMONIE-AROME cy46h1.

3.7.2. highlights from 2024

Operational perspectives. UWC-West went operational with a continuous EPS, based on HARMONIE-AROME cy43h2, where a 30+1-member ensemble is updated with 1 control and 5 perturbed members every hour.

For A-LAEF an operational upgrade to cy46t1 is planned for late 2024. The new version includes new ALARO-1 multiphysics, SPPT for ISBA prognostic fields and new diagnostic features (e.g. precipitation type and helicity).

C-LAEF in 1km horizontal resolution (cy46t1) has been tested for both winter and summer 2024 with good verification results. Operationalization is planned for 2025.

AROME-EPS Hungary has been tested with SPP perturbations and an upgrade to cy46t1 is expected in 2025.

AROME-EPS Météo-France will be upgraded to cy48t1 before the end of 2024. Random parameter perturbations have been tested with good results and are expected to enter the next e-suite based on cy49.

Research and development. The list of parameters that can be stochastically perturbed (using the SPP technique) has grown during the last year, and a paper has been published (Tsiringakis et al., https://doi.org/10.1175/MWR-D-23-0212.1). Testing of surface parameters and SLWIND perturbations are ongoing. The development of flow-dependent perturbations has been extended to include turbulence, shallow convection and orographic drag, where the flow-dependence is conditioned on TKE or 10m wind speed, in addition to microphysics parameters, where the flow-dependence is conditioned on cloud cover, see presentation by Endi Keresturi, DHMZ. Tests in C-LAEF 1km (Feb+Jun 2024) show a neutral to positive impact.

Post-processing and use of AI/ML. Many institutes are developing products that are targeted at the renewable energy sector, see e.g. presentation by Irene Schicker, GeoSphere Austria. Other products address extreme weather prediction, e.g. Météo-France developed detection of bow echoes and supercells. Users (and notably meteorologists) not only request probabilistic products, but also identification of possible scenarios to which end, e.g., clustering of ensemble precipitation forecasts are developed at Météo-France. Finally, development of generative AI to produce ensemble members conditioned on physics-based ensemble members has continued in 2024, and a paper has been submitted (Brochet et al., 2024).

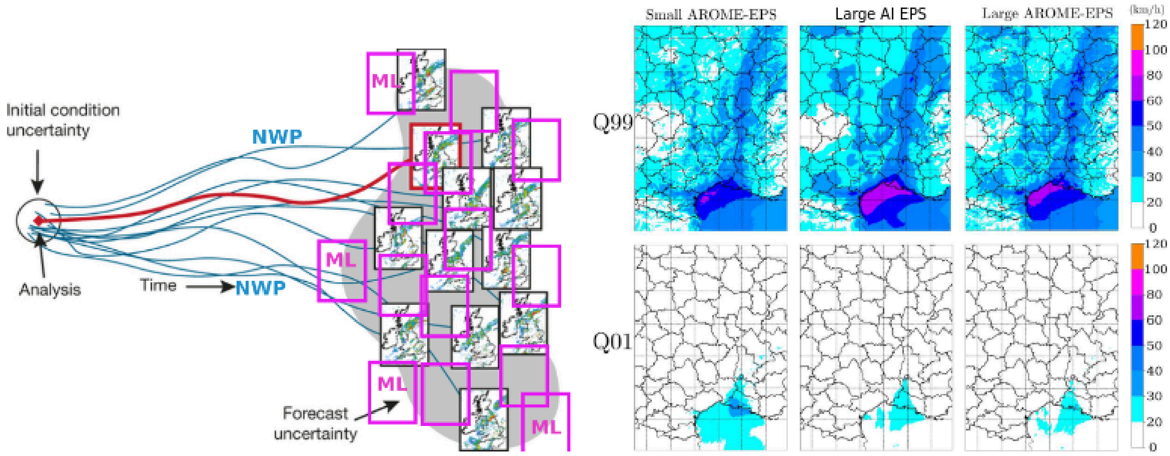


Figure 3.7.1: Ensemble augmentation with ML. The ML-augmented ensemble performs as well as a very large Arome-EPS, with significant gains on the estimation of extreme percentiles. Courtesy of Laure Raynaud, Météo-France.

3.7.3. perspectives and priorities for 2025

Exploration of AI/ML-methods for ensemble generation will continue in 2025 and will almost certainly have an impact on the future design of ensemble systems. This includes development that is not part of ACCORD (but still includes ACCORD members). If ACCORD wants to remain in the lead of limited-area EPS, we must keep up-to-date about these developments and adapt our plans accordingly.

One of the top priorities in phase 1 of ACCORD is closer collaboration across families. For EPS this has happened through exchange of ideas and methodologies, but this approach requires substantial porting of code. Therefore, the implementation of common SPP in AROME and

HARMONIE-AROME in cy49t1 is an important step forward that should be continued in 2025. Development of common scripting would be another important step that could facilitate closer collaboration across families. Common scripting is expected to be included in the 2026-30 strategy, but introductory steps should be taken already in 2025.

When developing parameter perturbations it is crucial to understand the sensitivity to the perturbations. To this end the URANIE framework for verification, validation and uncertainty quantification has been integrated into HarmonEPS, not least thanks to the successful scientific visit mentioned above. However, so far only two people are knowledgeable about this configuration, and they are busy with many other activities. In addition, it has been difficult to find staff with time to contribute to this task, so there is a risk that we will not be able to take advantage of the work done so far. The plan to use URANIE with MUSC (which would be much cheaper to run than the URANIE/HarmonEPS combination) may also have to be postponed.

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

3.8.1. overview of the activity in the area

A high level of activity within the MQA area has been seen in 2024: there were 5 MQA-related articles in the latest edition of the ACCORD Newsletter (nr 5). ACCORD staff delivered 8 and 5 presentations in the MQA-sessions of the All Staff Workshop and EWGLAM meeting, respectively. Details about efforts and achievements within the area to be found in a series of annual progress reports available on the ACCORD wiki:

https://opensource.umr-cnrm.fr/projects/accord/wiki/Meteorological_Quality_Assurance

Harp has become widely used for forecast verification in operations and in research. Several new teams have joined the user community by implementing their own workflows based on harp, and harp-based workflows are also used for evaluating the extreme digital twins in the frame of Destination earth. A comprehensive set of scripts for deterministic and probabilistic point-verification, initially developed by UWC-W, is shared on Github as https://github.com/harphub/oper-harp-verif. The third **harp training course** during ACCORD was held as a hybrid event in Dublin in March 2024, with 19 participants on site and 18 registered remote participants. There were sessions on reading data, point verification, spatial verification, script writing and visualization as well as some sessions where common user issues, such as local grib tables, were covered. The course was based on the first properly tagged release, harp 0.2, representing the culmination of major efforts towards stability and user friendliness through improved error catching, error messaging and inline documentation. New functions to aid verification in a production environment will be present in the imminent next harp-release, harp 0.3. The new run_point_verif() function handles reading data, error checking, computing scores and the saving of results, so that verification can be done with a single function rather than following a workflow.

The **Panelification tool** developed at geosphere Austria is suited for verification of extreme precipitation events by allowing easy comparison of forecasts to earth observations from radars or satellites. During an ACCORD **scientific visit** from Austria to Denmark the tool, originally written in python, has been interfaced with harp using the reticulate package, and is about to be added to the capabilities of oper-harp-verif.

Feature tracking is another powerful methodology for assessing high-resolution forecasts of high impact weather and diagnosing processes of moist physics. During a **scientific visit** from Spain to Norway the Tobac package of python was interfaced with harp and made available on github.

As a step on the way to intensify the **exchange between operations and research**, collection of feedback from user representatives nominated for the purpose was initiated. Feedback is collected using an electronic form where the representatives are invited to give feedback in the form of *use cases* exemplifying typically or persistently problematic (or well forecasted) meteorological phenomena or particular cases. So far, two such reports have been filed and are being considered by the ACCORD management team.

3.8.2. highlights from 2024

Exploiting the synergies with data assimilation

Significant progress has been made within UWC-West to utilise the data assimilation framework for verification thanks to work carried out within ACCORD (e.g. Eoin Whelan (Met Éireann), Magnus Lindskog (SMHI), and others). A development suite is currently running in real-time which generates sqlite tables containing observations from various sources (e.g. TEMP, BUOY, SHIP, ASCAT, AIREP etc) and the corresponding forecasts from the operational DINI model. This “Verification by Screening” approach naturally addresses the issue of radiosonde drift correction and can provide information on model performance which is typically not available from standard SYNOP verification (e.g. wind speeds over sea).

The sqlite tables are read directly into R and then passed to harp (e.g. det_verify) for verification purposes. A set of scripts for the verification and visualisation of these new observation sources is under development within UWC-West. A sample set of plots looking at AIREP temperature data are illustrated below (based on a limited sample size). Handling such observations obviously raises its own set of challenges (e.g. the inhomogeneity in observations as a function of height).

Please see Eoin Whelan’s presentation at EWGLAM for more information.

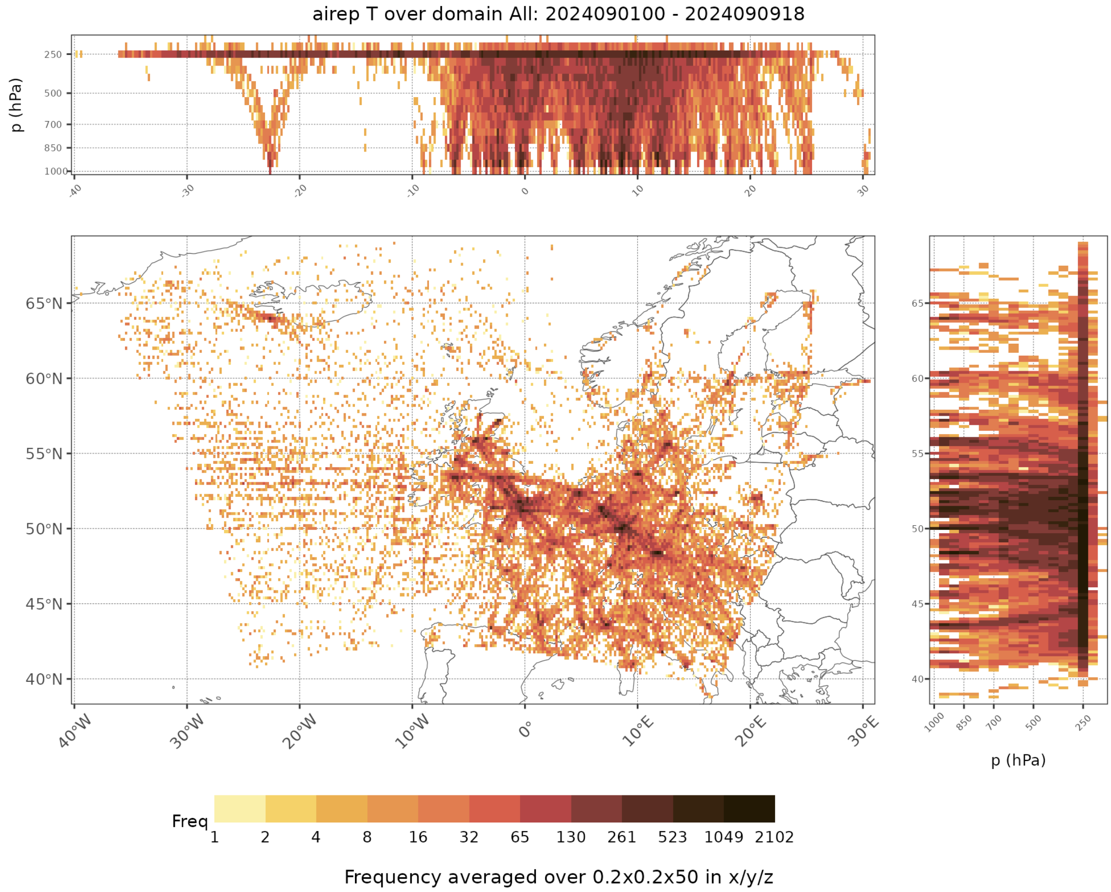


Figure 3.8.1: Sample observation frequency of AIREP temperature data over the DINI domain for the start of September. Lat/lon profiles are given on the right/top.

Lagrangian forecast evaluation

Identifying and tracking the movements of features, such as convective cells is an efficient way to verify forecasts at very high resolution against earth observations from radars and satellites. Using feature tracking to study the occurrence and life cycles of motion systems in models and in nature one can assess the models ability to predict related weather phenomena and make inferences about the representation of related physical processes in the models, in ways that would be difficult to achieve based on spatial and temporal statistics alone. A Lagrangian evaluation of convective activity in VHR forecasts, making use of the Tobac python package, was presented by Juan Jesús Gonzáles Aleman at the 2024 EWGLAM meeting. During a scientific visit to Norway, the main functionalities of Tobac were made available in the harpTobac package. The package website https://harphub.github.io/harpTobac includes reproducible worked examples using data from the MET Norway thredds server and an already regridded satellite dataset that is included with the package. The figure shows the movement of OLR-features corresponding to three different threshold values during 24 hours in a forecast initiated at 00 UTC 27 May 2024.

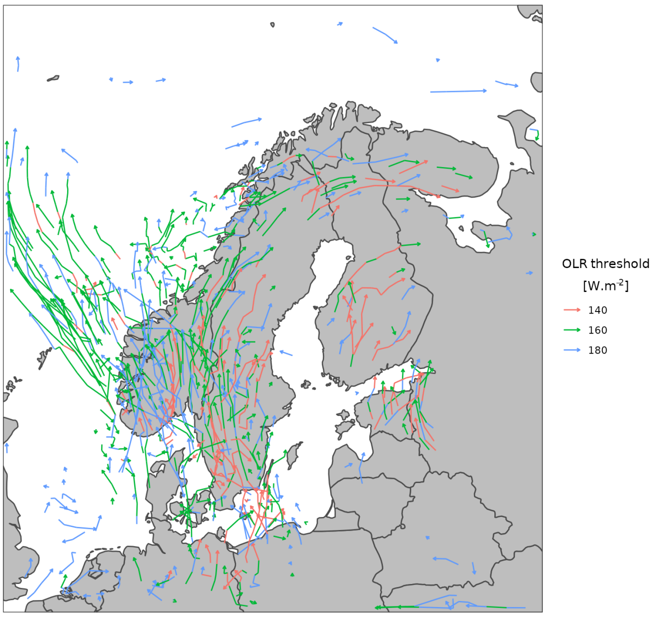


Figure 3.8.2: The movement of OLR-features corresponding to three different threshold values during 24 hours in a forecast initiated at 00 UTC 27 May 2024. For further details, see https://harphub.github.io/harpTobac

3.8.3. Perspectives and priorities for 2025

Despite the wealth of metrics, data, and software suited for the verification of high-resolution forecasts and validation of forecasting systems, forecasts are still being verified, and models validated, chiefly against data from reporting surface weather stations and sounding stations, unable to capture many, or even most, of the phenomena responsible for high impact weather chiefly targeted by ACCORD forecasting systems. The common verification software harp supports spatial verification methods, and recent interfacing to python-based tools such as Panelification developed by Geosphere Austria or feature tracking based on the Tobac package are paving the way towards process-oriented verification, while exploiting methods hitherto used only in the context of data assimilation offer to widen the spectrum and raise the amount of available verification data to totally new levels. Making use of these capabilities in verification of operational forecasts and evaluating new developments should be a priority for MQA in 2025.

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

3.9.1. overview of the activity in the area

This section outlines the progress in five key work packages: Code Optimization (**SY1**), Maintenance and Development of the Harmonie Reference System (**SY2**); and because one of the objectives of ACCORD is to improve collaboration between partners, this objective is further specified in three work packages: **COM2.1** (Code generation and maintenance: regular upkeep and updates, official releases), **COM2.T** (Code generation and maintenance: transitioning to new work practices and environments), and **SY4** (Towards a more common working environment: explore practical choices, prototyping, scripting).

3.9.2. highlights from 2024

Code Optimization (SY1) focuses on identifying and addressing computational performance bottlenecks using profiling and benchmarking techniques. Recent trends favor hybrid, coprocessor-based systems for improved economic and energy efficiency. Significant work has been done to evaluate refactored code performance on vector accelerator HPC systems. One example of this is the use of a simplified benchmark for parallel systems applied for different architectures.

The Arome and Harmonie-Arome systems can compile and run codes in single precision (SP), double precision (DP), and dual precision, allowing for mixed precision simulations. Early tests in operational environments show SP computations can enhance speed by 30-40%. The URANIE platform is being used to assess SP's impact systematically.

New algorithmic demands, such as the 4DVar data assimilation technique, require profiling and optimization for operational use. Additionally, software containers have been developed to streamline deployment across various computational architectures.

Maintenance and Development (SY2) of the Harmonie Reference System involves creating new releases based on CY46T1, while ensuring integration with previous versions for consistency. Meteorological validation for the harmonie-46h1.1 was done and a new release will be tagged by the end of 2024. Also a new development has started in parallel with CY49T2 as base code.

The HIRLAM community has adopted a paid plan on GitHub for source code management, enhancing collaboration and code quality. A new git workflow has been established for CY49 based directly on forking CY49T2 for the source codes and separating from them the scripting and tools in order to create a dev-49T2h version. In this dev version the needed code adaptations can be considered as a direct branch from CY49T2 in IAL forge. For this purpose a so-called Tiger Team of area experts has been formed to collaborate with the code integration of the missing harmonie-46h1.x components and new functionalities. Training on Git and associated workflows has been planned, and will be carried out to introduce best practices for using GitHub effectively within this new workflow.

The compilation strategy using CMake has been implemented to improve compilation efficiency and portability. A coordination action has been started to discuss a possible single implementation of CMake between the partners.

Code generation and maintenance (COM2.1) work package has made significant strides in common code generation, culminating in the establishment of the release of 3 cycles based on CY49 and a export based on CY48:

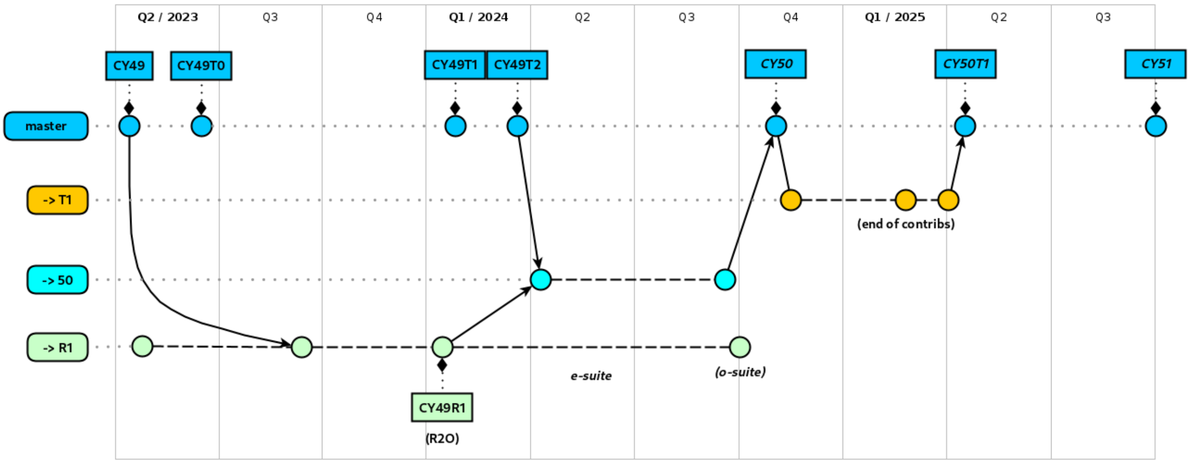


Figure 3.9.1: Overview of timing of cycles and code integration process

- CY49T1: released on January 9th, it is the gathering of ACCORD contributions collected during the fall of 2023
- CY49T2: released on April 3rd, it contains mostly refactoring in preparation for GPU adaptation
- CY50: released on October ??th, it is the merge of CY49T2 from MF/ACCORD and CY49R1 from ECMWF. It also includes the move of LAM spectral transforms to ectrans standalone package.

In addition, an "Export version 48T3" has been released on September 2nd, and contains additional material on top of CY48T3, to help with local implementation.

Transitioning to new work practices and environments (COM2.T) This year, new work practices were adopted, including systematic testing through the Davai tool and contributions via the ACCORD forge on GitHub. These changes have streamlined the workflow, allowing for over 100 contributions to CY49T1, enhancing visibility, revision management, and branch validation.

The technical validation process relies on unit tests from the DAVAÏ tool, which tests various code versions through a series of automated steps. This validation is vital for integrating and validating code changes, and the testing infrastructure has been adapted to evolving needs. An interface on the Météo-France and ECMWF platforms facilitates a more portable use of the DAVAÏ tool.

To support ongoing development, two DAVAÏ Contributors-Developers Working Weeks were held and another one is planned for November 2024. Additionally, common computational resources are provided through an ECMWF SPFRACCO Special Project to ensure effective testing of contributions

(SY4) Towards a more common working environment exploratory phase analysis has started. DEODE Scripting has been evolving rapidly and will include EPS capabilities in phase 2 of the project. This scripting is accessible to all partners because it does not infringe Intellectual Property Rights (IPR) within the Destine Earth initiative. A knowledge transfer within DEODE has been initiated and some ACCORD members attended the first training organised in Toulouse. A strategy for the co-development of components currently not included in scripting, such as data assimilation, has yet to be elaborated.

3.9.3. perspectives and priorities for 2025

The perspectives read as follows:

- Consolidate the methodologies for code generation and maintenance while ensuring the ongoing development of official model releases and the necessary transfer of knowledge.
- Investigate solutions and create a shared platform for information exchange, along with defining a quality assured "all-CSC" export code version.
- Code optimization will primarily focus on single precision and adaptations to enhance GPU performance (SPTR1) for better economic and energy efficiency.
- HIRLAM will continue to implement a multi-repository strategy to unify working practices and increase code visibility within the ACCORD forge.
- Facilitate knowledge transfer among different scripting systems and explore potential synergies, as well as establish procedures for the design and co-development of certain components.