SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	July 2023 – Jun 2024
Project Title:	HIRLAM-C 4th phase (2023-2025) Special Project
Computer Project Account:	Spsehlam
Principal Investigator(s):	J. Onvlee
Affiliation:	KNMI
Name of ECMWF scientist(s) collaborating to the project (if applicable)	………………………………………………………………… …………………………………………………………………
Start date of the project:	1 January 2023
Expected end date:	31 December 2025

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	40 MSBU	40MSBU + HIRLAM SBU pool resources	40 MSBU	Close to zero still (much use expected in second half of 2024)
Data storage capacity	(Gbytes)	20.000		20.000	20.000

Summary of project objectives (10 lines max)

Special project resources are primarily used for pre-operational assessment and full integration testing. Main areas of attention in 2023-2025:

- Complete the refactoring and code adaptation of Harmonie-Arome for alternative HPC architectures
- Integrate all assimilation algorithms developed for Harmonie-Arome in the OOPS framework. Assess 3/4D EnVar and all-sky radiance assimilation, optimize assimilation for nowcasting, and work towards coupled atmospheric/surface data assimilation. Include new (esp. surface) remote sensing observations.
- Develop and assess hectometric scale and nowcasting (ensemble) setups, with focus on urban aspects
- Develop, and assess the impact of, more realistic descriptions of the microphysics, radiation, use of real-time aerosol, stochastic physics, new or improved surface model components and surface physiography.
- Build experience with machine learning applications, including emulation of the full Harmonie system.

Summary of problems encountered (10 lines max)

Running longer experiments for integration testing of new model components has been rather problematic for our researchers in 2022 and 2023, due to the many changes in the research working environment in Bologna. The unfamiliar and unstable environment has resulted in crashes and delays in many of our longer experiments and has forced users to switch to local facilities for longer model runs. Relatively slow retrievals from MARS have also been causing problems with some regularity.

Summary of plans for the continuation of the project (10 lines max)

At the end of this project (Dec. 2025), the HIRLAM-C programme will be terminated. After that, a new Special Project for similar purposes might be initiated by the United Weather Centers, but this is still uncertain.

List of publications/reports from the project with complete references

- Bessardon, G., et al., 2023: "ECOCLIMAP-SG+: an agreement-based high-resolution land use land cover dataset for meteorological modelling", subm. to ESSD
- Brekel, S. van den, 2023: "Validating the surface flux ECUME and ECUME6 parametrizations used in the Harmonie model, M.Sc. thesis TU Delft. https://doi.org/10.5281/zenodo.8276789
- E.I.F. de Bruijn, F.C. Bosveld, S. de Haan, G.-J. Marseille, A.A.M. Holtslag, 2023: "Wind observations from hot-air balloons and the application in an NWP model." https://doi.org/10.1002/met.2128
- Lindskog, M., Azad, R., de Haan, S., Blomster, J., Ridal, M., 2023: "Impact of Mode-S Enhanced Surveillance Weather Observations on Weather Forecasts over the MetCoOp Northern European Model Domain", JAMC vol.62, no.8, https://doi.org/10.1175/JAMC-D-23-0009.1
- Maalampi, P., 2024: " Studying the effect of a new aerosol option on HARMONIE-AROME sea fog forecasts ", Helsinki University M.Sc Thesis, http://urn.fi/URN:NBN:fi:hulib-202403111471
- Martín Pérez, D., Gleeson, E., Maalampi, P., Rontu, L. 2024: Use of CAMS Near-Real-Time Aerosols in the HARMONIE-AROME NWP Model. *Meteorology* **2024**, *3*, 161-190. https://doi.org/10.3390/meteorology3020008
- Mile, M., Guedj, S., Randriamampianina, R., 2023: "Exploring the footprint representation of microwave radiance observations in an Arctic limited-area data assimilation system", Geophys. Model Dev. https://gmd.copernicus.org/preprints/gmd-2023-195/
- Oskarsson, J., Landelius, J, Lindsten, F., 2023: "Graph-based Neural Weather Prediction for Limited Area Modeling", 2309.17370 (arxiv.org)
- Ridal M. et al. 2024: "CERRA, the Copernicus European Regional Reanalysis system", subm. to QJRMS (Manuscript QJ-23-0244, under review).
- Ridal M., J. Sanchez-Arriola, M. Dahlbom,2023: "Optimal use of radar radial winds in the HARMONIE numerical weather prediction system", Journal of Applied Meteorology and Climatology, https://doi.org/10.1175/JAMC-D-23-0013.1
- Rieutord, T., Bessardon, G., Gleeson, E., 2024: "ECOCLIMAP-SG-ML: ensemble land cover maps for numerical weather prediction", subm. to ESSD

- Suomi, J., et al., 2024: “Evaluation of surface air temperature in the HARMONIE-AROME weather model during a heatwave in the coastal city of Turku, Finland”. Urban Climate, Volume 53, 101811, ISSN 2212-0955, https://doi.org/10.1016/j.uclim.2024.101811
- Saranko, O., et al., 2024: “Comparison of physically based and empirical modeling of night-time spatial temperature variability during a heatwave in and around a city.” Subm. to JAMC
- A.C.M. Savazzi , L. Nuijens, W. de Rooy, M. Janssens, A.P. Siebesma, 2023: “Momentum Transport in Organized Shallow Cumulus Convection.”, J.Atm.Sc. 81 p.279-296, https://doi.org/10.1175/JAS-D-23-0098.1
- Tsiringakis, A., et al., 2024: “An Update to the Stochastically Perturbed Parametrizations Scheme of HarmonEPS”, accepted by MWR
- Venstad, T., Batrak, Y. and Remes T. , 2024: “Impact of improved physiography data on hectometric weather forecasts in Svalbard”. MET Report 9/2024, ISSN 2387-4201, https://www.met.no/publikasjoner/met-report

Summary of results (from July 2023 to June 2024)

The HIRLAM-C research programme (January 2016 - December 2025) is a research cooperation of the national meteorological institutes of Denmark, Estonia, Finland, Iceland, Ireland, Lithuania, Netherlands, Norway, Spain and Sweden. Common research efforts are focused on the scientific development and implementation of the mesoscale analysis and forecast system Harmonie, and its associated ensemble prediction system HarmonEPS. Operational Harmonie model configurations are run locally in three subgroups of HIRLAM services: the MetCoOp collaboration (Norway, Sweden, Finland, Estonia, Lithuania and Latvia), the UWC-West collaboration (Denmark, Iceland, Ireland, and Netherlands), and AEMET (Spain). A Harmonie Reference system is being maintained on the ECMWF ATOS platform.

The computational resources for the HIRLAM-C Special Project at ECMWF are primarily used for pre-operational validation and verification of new model features and for meteorological performance assessment of new cycles of the Reference System, with a focus on the main domains of the three operational subgroups MetCoOp, UWC-West and AEMET. In addition to these special project resources, the HIRLAM services yearly create a common pool of SBU resources at ECMWF for scientific experimentation.

Below, the main R&D and testing activities in the fields of data assimilation, the atmospheric forecast model, surface analysis and modelling, ensemble forecasting, machine learning activities and code efficiency and system aspects during the past year are outlined.

A) Data assimilation

A1: Development, operationalization and optimization of flow-dependent data assimilation methods

Work on data assimilation algorithms in the second half of 2023 has focussed on upgrading the 4D-Var system to Harmonie Cy49T1h and to enable it to run stably and efficiently with all available observations types, still in the MasterODB code framework. Extensive integration and performance testing of 4D-Var vs 3D-Var under MasterODB in Harmonie Cy46h1 has been done pre-operationally in MetCoOp and AEMET, and will be done by UWC-West later this year. From early 2024 onwards, attention has shifted to getting 4D-Var to function properly in the new OOPS data assimilation framework. This integration into OOPS has been largely completed. In the coming year, also the hybrid EnVar formulation is expected to be integrated in OOPS.

A second priority area has been to start assessing the performance of the 3D-Var and 3D-EnVar systems in the OOPS framework. Work is ongoing to expand them with the full set of operationally available observations and to study the potential value of adding new types of control variables, particularly for hydrometeors.

A2: Optimal use of (high-density) atmospheric observations

On the observations side, progress continues to be made in enhancing the utilization of observations from existing and new satellites. At present, the Harmonie 3D-Var- and 4D-Var assimilation systems are able to assimilate operationally conventional data, cloud-free IR and microwave radiances from e.g. AMSU-A, AMSU-B, MHS, CRiS and IASI, radar radial wind and reflectivity volume data, GNSS ZTD, STD and gradient products, GPS-RO, SEVIRI IR and WV observations, Mode-S data, AMV's and winds from several scatterometer instruments. Improvements have been made in the quality control and bias correction for e.g. radar radial winds, GNSS STD and gradient data, and observations from private weather stations and smart phones. An improved treatment of surface-sensitive low-peaking channels has led to an enhanced use and positive impact of these data for all three operational subgroups in HIRLAM (an example is given in fig.1 below for MetCoOp).

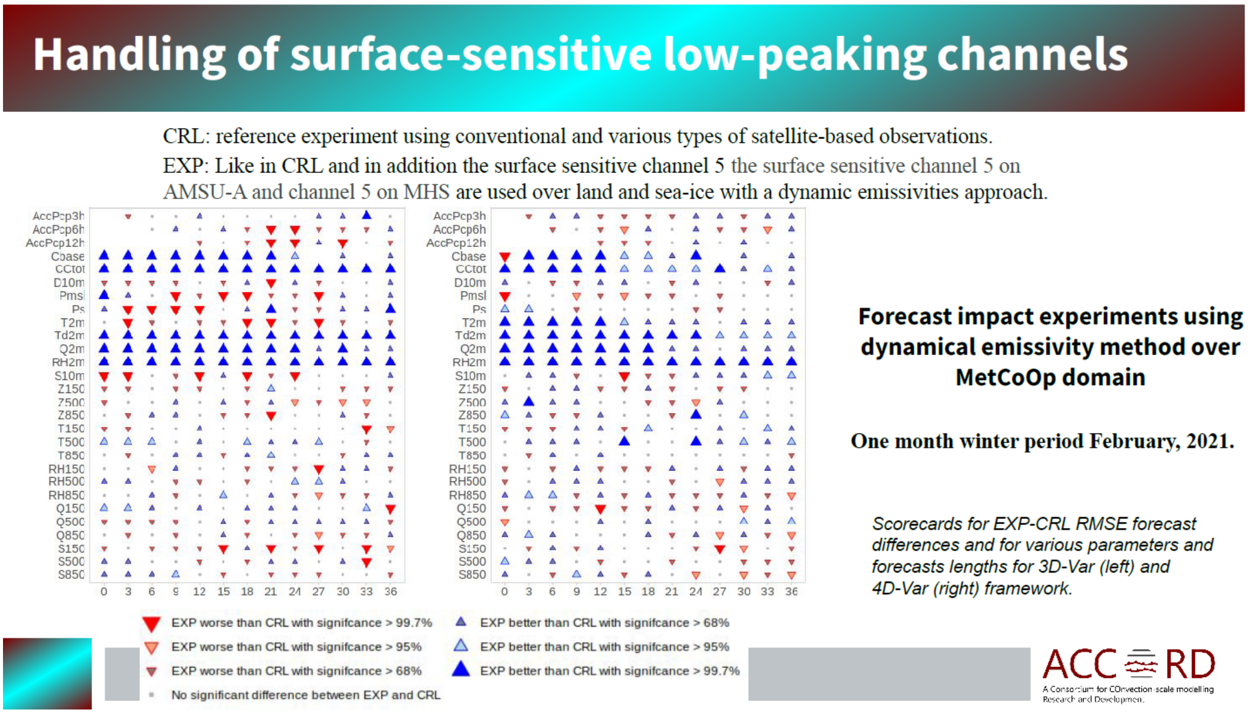

Fig. 1. Example of the impact of adding the surface-sensitive channel 5 on AMSU-A and MHS over land and sea ice with a dynamic emissivity approach on top of the observations used by default in Harmonie over the MetCoOp domain before mid-2023. The two scorecards show the overall positive impact of the additional assimilation of these data in 3D-Var (left) and 4D-Var (right). Courtesy: M. Lindskog.

Efforts on the assessment of all-sky microwave radiances assimilation are being strengthened significantly in 2024. Work has continued on the preparation for future satellites and instruments like the Arctic Weather Satellite, MTG/IRS and EPS-SG/STERNA. The team participated in a Eumetnet/E-GVAP study to compare and combine GNSS ZTD, STD and gradients products in regional data assimilation, and assess their individual and combined impact; the results on assimilation of slant delays are a bit mixed over the various domains, so further tuning appears needed.

For radar reflectivities and radial winds, the impact of assimilation of the new NIMBUS 5 minute volume radar data for the MetCoOp, UWC-West and AEMET domains was assessed and found to be neutral. Feedback on issues encountered with radar quality control and need for radar metadata has been given to OPERA. For ground-based observations, several new features have been introduced in Cy46h1.2: the application of VarBC to ship surface pressure observations (optional, observed impact neutral), and the enabling of assimilation of smart phone observations in terms of both pressure and geopotential (optional). Because of their high spatial and temporal density over Europe, EMADDC Mode-S-EHS wind and temperature data require substantial thinning so as not to overwhelm the impact of other types of observations. Several methods for Mode-S thinning exist, and it has become clear that the manner of thinning really matters. This will be studied further.

<u>A3. Optimization of data assimilation setups at sub-km resolutions and for the nowcasting range</u>

For assimilation in sub-km (500m-750m) resolution model setups, the goal is to move towards sub-hourly cycling, assimilating data sources with sufficiently short latency (10-20min): SYNOP, EMADDC Mode-S, radar (NIMBUS), NetAtmo/WOW stations and various sources of (geo and polar) satellite data. Technically, sub-hourly cycling has been enabled and first experiences have been gained. The main aim this year is to experiment extensively with sub-hourly cycling setups and assess the challenges for assimilation on these scales in space and time, particularly the issue of model spinup.

For nowcasting, an improved cloud ingest system (taking into account more information on the depth of clouds) has been tested successfully in the nowcasting range, and has been made operational in the MetCoOp MNWC nowcasting setup. Experiments are ongoing to test whether MNWC should be run with its own data assimilation cycling, rather than use the first guess from the MEPS regional ensemble. 4D-Var is being assessed in local pre-operational sub-km resolution configurations. A centered Incremental Analysis Updates (IAU) initialization scheme has been added as an option in cy46h1 and Cy49T1.

For the progress on coupled atmosphere-surface assimilation, see section C (Surface).

B) Atmospheric forecast model

B1. Turbulence and shallow convection:

For shallow convection, a scale-aware convection parametrization has been developed to handle the grey zone where shallow convection is still only partially resolved. So far, this scheme has been showing very promising results in the representation of the spatial scales and the evolution of shallow convective clouds on a range of resolutions from several km to O(100m) and over several domains (see fig.2 for an example). Various options in the scheme (such as a threshold vertical velocity below which to switch off parametrized convection) are being assessed daily against boundary layer lidar and cloud radar observations and against LES.

For (very) stable boundary layer conditions, a stochastic turbulence parametrization may be needed to create realistic boundary layer clouds. Both an intrinsically stochastic turbulence scheme and a data-driven approach to derive a stochastic stability correction to model turbulence are being used to study the transition of turbulence from weakly stable to very stable conditions, and its impact on energy balances and profiles close to the surface.

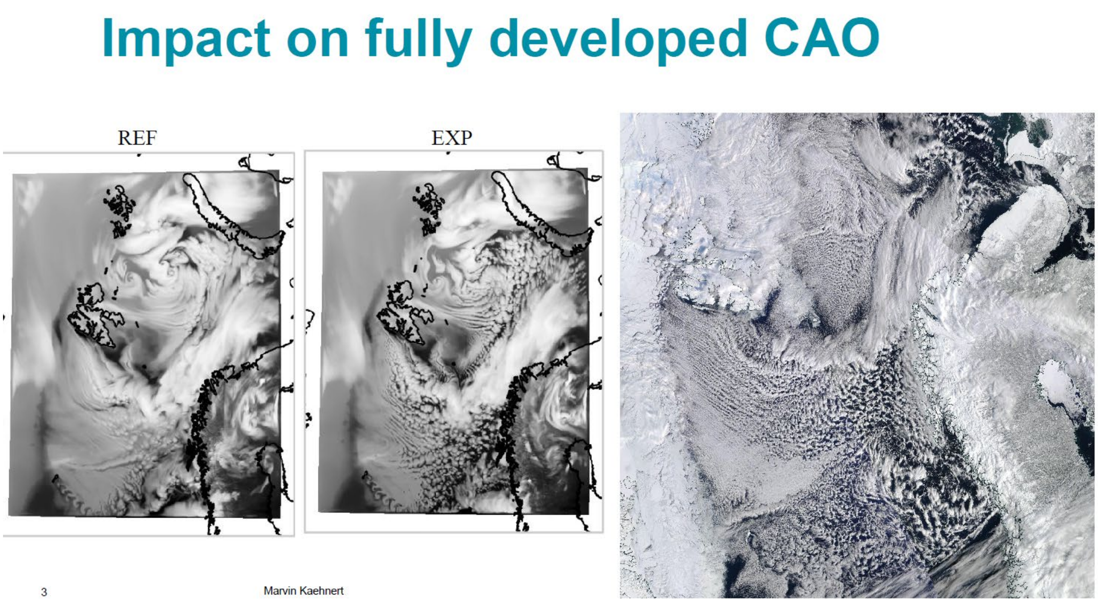

Fig.2: Impact of the threshold vertical velocity option in the scale-aware convection scheme for a cold air outbreak (CAO) case over the Arctic. The righthand side picture shows a satellite image of the cloud structures. The Reference Harmonie model (left) gives a rather smeared-out representation of the clouds. The scale-aware scheme is able to represent much better the development of the small-scale shallow convective clouds in this case.

B2. Improved representation of the cloud-radiation – microphysics- aerosol interaction:

The Cloud-Aerosol-Radiation (CAR) team has introduced a consistent workflow for the use of near-real-time (NRT) aerosol in the radiation and microphysics schemes as an option in Cy46h1.2 and in Cy49T1h.

In Cy46h1.2, the meteorological performance of the CAR setup continues to be validated carefully, in new 1- and 3D case studies for different domains and fog conditions, and against the cloud droplet number concentration (CDNC) profile formulation which presently still is the default. Generally, the NRT aerosol setup provides forecasts at least as good as the present default setup with climatological aerosol. The added computational cost of including NRT aerosol for all available aerosols in Harmonie Cy46h1.2 on ATOS is ~+23%. A more realistic option which is therefore being considered for operations is to use NRT aerosols only for very few important aerosol types, and to use CAMS climatologies for others.

Earlier, it has been shown that model cloud, convection and fog behaviour depend very sensitively on the assumptions made on cloud droplet size distributions. Sensitivity and diagnostic studies on the impact of different size distributions on model behaviour are being carried out in the context of URANIE and SPP perturbations in HarmonEPS (section D).

In Harmonie Cy49T1h, the ECRAD radiation scheme and LIMA second-moment microphysics will become available in fall 2024. Scientific validation of ECRAD and LIMA in Harmonie, e.g. against 1D-cases, dedicated field experiments and Cloudnet observations, will become a high priority then. One thing to be studied from 2025 onwards is the performance of radiative computations on a coarser grid than the remainder of the physics, something which may be particularly relevant for hectometric scale models. Sub-gridscale 3D cloud shading effects can be represented by the SPARTACUS scheme in ECRAD. To represent 3D cloud shading effects on hectometric scales, it is proposed to run ECRAD on a coarser grid (and timestep) than the rest of the forecast model, and use the fine-grid cloud fields to compute SPARTACUS inputs related to cloud variability.

B3. Sub-km resolution modelling

Meteorological assessment of several pre-operational sub-km models (500-750m resolution) is ongoing over about 10 domains. A vertical resolution increase from 65 to 90 levels has been shown to contribute to a good performance of many of those setups. Several 90 levels configurations are presently being used, with different choices for the lowest model level and number of layers close to the surface. Experiments are being prepared for testing more extensively on what would be optimal settings here.

In scientific experimentation, attention is mostly focused on the development and validation of hectometric (100-200m) resolution models in downscaling mode against supersites, Cloudnet data and LES runs. One of these setups is being run daily over the Netherlands and validated against both LES runs and boundary layer profile data from the Cabauw supersite. Aspects that have been studied include the cloud representation as a function of resolution throughout the shallow convection grey zone in a variety of shallow convection formulations (in particular the new scale-aware shallow convection scheme, see B1), the impact of increasing the horizontal and vertical resolution on boundary layer dynamics and thermodynamics, the impact of nesting and coupling hydrometeors, and the development and assessment of quasi-3D turbulence and radiation schemes. E.g. the Goger et al quasi-3D turbulence scheme was tested in this context and found not to have much impact.

Assessing and demonstrating the added value of models at such resolutions is quite challenging. On such small domains, the quality and age of the LBC is generally observed to be a dominating factor in forecast quality.

C) Surface analysis and modelling

C1: Improving the sophistication of surface model components

In the past years, many tests have been done with the new many-layer diffusion soil, extended snow and snow-over-vegetation schemes (DIF, ES, MEB) and the new SEKF assimilation scheme for soil and snow. Generally, in offline studies these schemes have been shown to perform clearly better than their predecessors. One remaining blocking point for operational implementation was the “drying issue” seen in ISBA-DIF: it shows too much bare soil evaporation, especially over the Iberian peninsula but also e.g. over agricultural areas within the MetCoOp domain. One possible solution which has been extensively investigated in the past months is the so-called “dry soil layer (DSL)” approach: adding such a hardened layer increases the surface resistance for evaporation from bare soil, and stores humidity in the soil throughout the year, which can then increase transpiration during summer. This DSL approach has been comprehensively tested against observations from special sites and against dedicated surface flux campaigns, over several domains, but sofar with mixed results. This remains under investigation.

Online simulations with the roughness sublayer (RSL) scheme of Harman and Finnegan (2007) for canopy-induced turbulent mixing, have been done over Iberia and Sweden. This parametrization includes the concept of displacement height, and a more advanced computation of the roughness length z_{0m} as a function of leaf area index (vegetation sparseness) and atmospheric stability. Extensive offline validation experiments have shown improved performance when applying the RSL scheme. The present online RSL studies are focusing on the use of roughness length and blending height for the lowest model levels.

The move to hectometric models has given a strong impetus to the preparation and validation of high-resolution physiographic maps and a focus of attention on model performance over urban areas. New physiographic datasets covering Europe at 60m resolution have been produced (Bessardon et al 2024, Rieutord et al. 2024), and validation against e.g. LUCAS and national data showed good performance (e.g. fig.3).

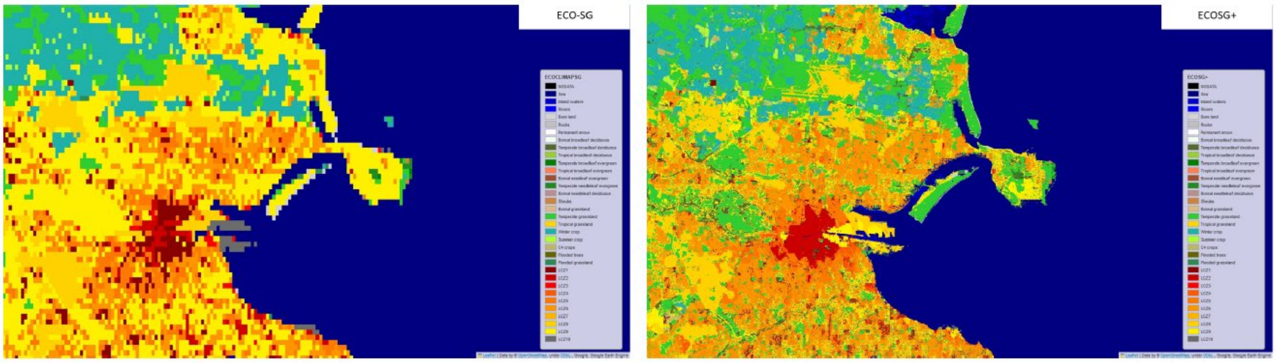

Fig. 3. An example of improvement of the ECOCLIMAP-SG land cover map in the Dublin region with AI: ECOCLIMAP-SG (left) and ECOCLIMAP-SG+ (right), based on a decision-tree method.

More advanced options in the urban TEB scheme are undergoing testing in urban environments throughout Europe, against urban observation networks and several dedicated urban observation campaigns, especially the PANAME campaign over Paris for the Paris Olympics. At present, in Harmonie there is a strict interface between the atmosphere and surface at the lowest atmospheric model level, where state variables and fluxes are interchanged. A new approach which may be more realistic for the treatment of very heterogeneous urban landscapes is that by Schoetter et al 2020, in which high buildings may interact with a number of the lowest model levels, depending on their height. Preparations have been made for detailed model verification and testing of the Schoetter et al approach at O(200m) resolution over urban areas, for a variety of cities with dedicated urban observation networks.

In the context of CARRA, improvements have been made in the sea ice model SICE concerning the representation of the mixed snow-ice layer, both over sea and lakes. These are being tested both offline and inline.

<u>C2. Enhanced use of satellite surface observations in combination with more advanced surface assimilation</u>

The new SEKF assimilation scheme which is being tested pre-operationally enables increased use of satellite surface products. Preparations are being made for the subsequent progressive inclusion and testing of satellite retrieval data in the SEKF surface assimilation: snow depth from Sentinel-1, OSI-SAF and MODIS sea ice concentration and sea ice surface temperatures, soil moisture from Sentinel-1 C-band SAR and Metop ASCAT, and retrievals from various satellites in lake data assimilation. In the past year, the focus has been on snow assimilation involving satellite snow extent observations, which is important in the cold season in areas where SYNOP snow cover stations are sparse or missing.   The so-called “snow barrel” method has been developed by FMI for improving the snow analysis by the use of satellite imagery of snow extent. This has been tested successfully and recently been made operational. Currently, most attention is given to assimilation studies involving sea ice concentration and sea ice temperatures.

Attention has been shifting towards the creation of a more advanced, strongly coupled atmospheric-surface data assimilation system, which is able to permit direct assimilation of e.g. satellite surface radiances. Presently, two roads to this are being pursued in parallel: an EnKF setup and a 3DEnVar framework, which is being studied in the context of CARRA. Work has also been done on coupling Harmonie with the ocean model NEMO, using an OASIS coupler. In the first instance, this will be validated in climate mode with the Harmonie climate model (HCLIM), rather than in NWP context.

D) Probabilistic forecasting

For the HarmonEPS ensemble system, the focus of scientific development remains on model perturbations using SPP, gradually shifting attention from atmospheric to surface parameter perturbations. SPP has been successfully tested and introduced in Cy46h1.2 as the default model perturbation scheme. New atmospheric parameters for which perturbations are being introduced are the size distributions of solid water species and hydrometeor terminal fall velocities. The parameter values which are adopted in the ICE3 microphysics scheme for these distributions and speeds have a large uncertainty, and under certain circumstances may strongly affect hydrometeor number concentrations, convective evolution, cloud dynamics, radiation and precipitation types and amounts. Perturbations for the fall velocities of rain, snow and graupel are being implemented In Cy46h1.2 and will be tested later this year. Other microphysics parameters for which perturbations are being investigated concern the shape of the gamma distribution used to compute the cloud droplet size distribution. Work has also been done on diagnostics of the impact of these perturbations on modelled hydrometeor counts and precipitation.

Good progress was made with technically extending SPP with surface perturbations of the heat and momentum drag coefficients. Experiments will be done over periods with stable boundary layer conditions to test whether these perturbations give sensible and expected results. Work on different options for perturbing LAI has continued. Experiments with perturbations of minimum stomatal resistance RSMIN and thermal inertia coefficient CV gave mixed results: while they increased the ensemble spread for T2m and RH2m, they also increased RMSE. This will need to be investigated further by validation for different sub-regions, additional time periods and different assumptions for the distributions of the perturbations.

In SPP studies, the URANIE tool has proven its value for identifying sensitive parameters to perturb, and for the assessment and tuning of perturbation length scales. The performance of different choices for cost functions (metrics like spread/skill ratio) in the URANIE optimizer has been tested. A new UranEPS setup has been created for launching URANIE sensitivity experiments for HarmonEPS.

E) Machine learning (ML)

Activities in this field have been developing very rapidly in the past year. Examples of applications of ML within the context of the NWP model itself are e.g. the work on ML-derived observation operators, the use of data-driven approaches to stochastic turbulence, speedup of the ECRAD radiative model, the improvement of physiographic maps, ensemble calibration efforts and the detection and tuning of sensitive model parameters. A Eumetsat fellowship on ML/MW satellite LAM DA has recently been selected and will start after summer. ML algorithms have been developed on semi-transparent cloud removal and fog detection.

In the fall of 2023, Linkoping University and SMHI presented a deterministic fully data-driven LAM model, Neural-LAM (https://github.com/joeloskarsson/neural-lam). Several other HIRLAM services have been joining these developments. A probabilistic version of the Neural-LAM is under development; first results on this have been presented last May. An alternative stretched-grid approach is being explored by MetNorway staff in the context of the ECMWF ML pilot project. Diffusion-based ensemble forecasting with generative AI appears promising. A methodology for enriching ensemble size while preserving dynamical and physical consistency is being investigated.

In order to make archived model data and existing re-analysis and reforecasting datasets more suitable for ML training efforts, a common tool has been created to transform these datasets from the customary GRIB format to Zarr. This tool will be included in the Harmonie Reference workflow.

F) Computational efficiency, portability and system aspects

Testing of single vs double precision has led to the adoption of single precision in large parts of the Harmonie-based model configurations. Options to further optimize the computational efficiency of 4D-Var will be pursued in parallel with a more extensive and targeted quality assessment. Other activities aiming at code optimization are primarily being pursued in the context of code refactoring (improving performance on GPUs) or of machine learning (e.g. in the radiation scheme).

In order to make the Harmonie code suitable for use on new/mixed computer architectures, the Fortran code is being refactored. This work has been delayed a bit due to the introduction of new coding norms; it is expected to be finished next year. After this, code adaptation tools can be applied to perform code optimization on specific architectures. For spectral transforms and machine learning emulation algorithms, this will be done by hardware-optimized external libraries and API's like the ECTRANS library developed by ECMWF. For grid point calculations, the semi-automatic code transformation tool LOKI will be used to generate hardware-specific code through e.g. loop re-ordering, memory layout etc. Experience with this is being gained. Further work will concentrate on making the refactored codes work together with a variety of compilers and to truly optimize computation efficiency for GPU's on specific machines.

In the context of the DE-330 project, a prototype python-based scripting system has been developed which can run the Harmonie-Arome forecast model, and a beginning has been made with basic scripts for data assimilation. In the remainder of this special project phase, more and more parts of the present Harmonie-Arome scripting system will be replaced gradually by Python-based components.

The latest official Harmonie-Arome release, Cy46h1.2, has been made early 2024 after extensive integration testing and meteorological assessment on ATOS. Cy46h1.2 contains the following new features:

- Data assimilation and use of observations: adaptations in 4D-Var; technical implementation of all-sky radiances, the footprint operator for radiances, and the cloud initialization system for nowcasting; optional inclusion of GNSS STD/gradients data;
- Atmospheric physics: introduction (optionally) of a Thompson-based microphysics scheme ICE-T, alterations in the forecast model workflow for consistent use of near-real-time CAMS aerosols, and the Fitch et al. and EWP wind farm parametrizations;
- Surface: ECUME as default sea flux scheme; a technical implementation of the many-layer soil and snow modules in combination with the SEKF surface assimilation scheme; physiography updates.
- HarmonEPS: SPP as the default scheme for model perturbations; extensions in the number of atmospheric and surface parameters available for SPP;
- Technical developments: cmake as default compilation tool; scripting changes permitting sub-hourly cycling, single precision, and a Harmonie 3DVar system with conventional observations under OOPS.

The next Harmonie release, Cy49Th1, is presently under construction and technical validation, and as this is a big effort, there have been few meteorological performance experiments done yet this year using special project resources. However, meteorological testing with this new code version is expected to start after the summer of 2024. Harmonie-specific innovations in Cy49Th1 which will be tested using the special project 2024 SBU resources on ATOS are: the refactored Harmonie forecast model code; 4D-Var in the OOPS framework; recent changes in the use of observations (esp. all-sky radiances treatment); the scale-aware shallow convection scheme; the near-real-time cloud-aerosol-radiation-microphysics workflow; the Roughness Sub-Layer (RSL) and Dry soil Layer (DSL) options in the ISBA-DIF soil scheme; and the new atmospheric and surface model perturbations added to the SPP scheme. Component and integration testing of these innovations will commence in the second half of this year. In addition, extensive experimentation and validation efforts will be performed for Harmonie in combination with the new ECRAD radiation scheme and the various options in the LIMA second moment microphysics.