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	Jul 2021 – June 2022
Project Title:	HIRLAM-C 3d phase (2021-2022) 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 2021
Expected end date:	31 December 2022

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	40 MSBU	40 MSBU	21.5 MSBU
Data storage capacity	(Gbytes)	22.000	22.000	22.000	22.000

Summary of project objectives (10 lines max)

The main areas of attention are:

- introduction and optimization of flow-dependent assimilation techniques (4D-Var, 3/4DEnVar)
- increasing the range and impact of high-resolution and remote sensing data to be assimilated (esp. all-sky radiances, crowd-sourced observations and satellite surface observations)
- improvement of the model behaviour for fog, convection initiation and stable boundary layer conditions
- a more sophisticated description of radiation-cloud-microphysics-aerosol interactions
- introduction of a more sophisticated surface analysis and modelling system,
- development of hectometer-scale resolution Harmonie setups and O(10m) physiographic databases.
- Computational efficiency and code portability

Summary of problems encountered (10 lines max)

Running experiments has been rather slow in the past months, due to the many changes in the research working environment and the not yet fully stable BOND setup. Even with an advance team that started work on the AA machine in an early stage, this somewhat unstable environment is resulting in delays in quite many of our experiments. However, excellent user support from ECMWF as usual.

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

In the period until end 2022, the main priorities will be:

- the testing of integrated pre-operational configurations for the overhaul of the surface analysis and modelling system and the introduction of aerosols parametrizations and near-real-time CAMS aerosol data
- Introducing OOPS version of 3- and 4D-Var and optimizing assimilation for use in the nowcasting range
- increased use of very high resolution third-party data and satellite surface observations
- alleviating forecast model deficiencies, with focus on fog, stable conditions, and surface characteristics
- the development of hectometric scale and nowcasting ensemble setups, with focus on urban aspects
- refactoring of the Harmonie forecast model in preparation for future HPC architectures
- building experience with machine learning in all parts of the Harmonie system
- and enhancing computational efficiency, scalability and portability.

List of publications/reports from the project with complete references

J. Chen, et al., 2021: Quality control and bias adjustment of crowd-sourced wind speed observations. *QJRMS*, https://doi.org/10.1002/qj.4146

C. Clancy, Fannon, J., Whelan, E., 2022: Hectometric scale experiments at MetEireann, ACCORD Newsletter 2, p.129-138.

J. Díaz-Fernández, P. Bolgiani, D. Santos-Muñoz, L. Quitián-Hernández, M. Sastre, F. Valero, J.I. Farrán, J.J. González-Alemán, M.L. Martín, 2021: Comparison of the WRF and HARMONIE models ability for mountain wave warnings. *Atmospheric Research* (under review)

Filioglou, M., et al., 2022: Evaluating modelled winds over an urban area using ground-based Doppler lidar observations. Met. Appl., https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/met.2052

Frogner, I.L., et al., 2022, Model uncertainty representation in a convection-permitting ensemble – SPP and SPPT in HarmonEPS. MWR 150, p.775-795, https://doi.org/10.1175/MWR-D-21-0099.1

S. Hagelin et al., 2021: Evaluating the use of Aeolus satellite observations in the regional NWP model Harmonie- Arome, Atmos. Meas. Tech., vol. 14, p.5925-5938, https://doi.org/10.5194/amt-14-5925-2021

Homleid, M., 2022: Improving model performance in stable situations by using a pragmatic shift in the drag calculations – XRISHIFT. ACCORD Newsletter 2, p. 96-108

Keany, E., Bessardon, G., and Gleeson, E., 2022: Using machine learning to produce a cost-effective national building height map of Ireland to categorise local climate zones, Adv. Sci. Res., 19, 13–27, https://doi.org/10.5194/asr-19-13-2022,

M. Mile, Azad, R., Marseille, G.-J., 2022: Assimilation of Aeolus Rayleigh-Clear Winds Using a Footprint Operator in AROME-Arctic Mesoscale Model, Geophys. Res. Letters, https://doi.org/10.1029/2021GL097615

B. Palmasson, Pedersen, G.N., Thorsteinsson, S., Yang, X., 2022: Hectometric experiments with the Harmonie-Arome system at IMO, ACCORD Newsletter 2, p.139-146

J. Poulsen, Yang, X., Whelan, E., 2021: Porting Harmonie-Arome to a public cloud cluster – AWS, ACCORD Newsletter 1, p. 164-169

de Rooy, W.C., Siebesma, P., Baas, P., Lenderink, G., de Roode, S., de Vries, H., van Meijgaard, E., Meirink, J.-F., Tijm, S., and van 't Veen, B., 2021: Model development in practice: A comprehensive update to the boundary layer schemes in HARMONIE-AROME. *Geophys. Model Dev. https://doi.org/10.5194/gmd-15-1513-2022*

B.H.Sass, 2021: A scheme for verifying the spatial structure of extremes in numerical weather prediction: Exemplified for precipitation - Sass - 2021 - Meteorological Applications - Wiley Online Library

M. Shapkalievski et al., 2022, Introducing a roughness sublayer in the vegetation-atmosphere coupling of Harmonie-Arome, ACCORD Newsletter 2, p.82-90

D. Suárez-Molina and J. Calvo, 2021: Very high-resolution experiments at AEMET. *ALADIN-HIRLAM Newsletter* 16, p.106, www.umr-cnrm.fr/aladin/IMG/pdf/nl16.pdf

M., Tijhuis, Theeuwes, N., Barkmeijer, J., 2022: The representation of turbulent kinetic energy in Harmonie-Arome at hectometer scale, ACCORD Newsletter 2, p. 115-128

Walsh, E., Bessardon, G., Gleeson, E., and Ulmas, P., 2021: Using machine learning to produce a very high resolution land-cover map for Ireland, Adv. Sci. Res., 18, 65–87, https://doi.org/10.5194/asr-18-65-2021.

Xiaohua Yang and Henrik Feddersen, 2021: Benefit of early delivery ASAP data to LAM forecasts, *ALADIN-HIRLAM Newsletter* 16, p.45, www.umr-cnrm.fr/aladin/IMG/pdf/nl16.pdf

Summary of results (from July 2021 to June 2022)

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. Since January 2021, the HIRLAM-C cooperation forms part of the wider ACCORD consortium. Within HIRLAM-C, research efforts are focused on the development and implementation of the mesoscale Harmonie model, and its associated ensemble prediction system HarmonEPS. A Harmonie Reference system is maintained on the ECMWF HPC platform. Computational resources for the HIRLAM-C Special Project at ECMWF are used for experimentation with, and evaluation of, newly developed elements for this Reference System. A set of pre-operational tests for Cy43h2.2 has recently started and will continue this summer, among others with full ensemble tests. Below, the main research and testing activities in Harmonie data assimilation, atmospheric modelling, surface analysis and modelling, ensemble forecasting and code efficiency and portability aspects during the past year are outlined.

A) Data assimilation

<u>A1: Development, operationalization and optimization of flow-dependent data assimilation methods</u>
The focus of activities in the past year has been on bringing the Harmonie 4D-Var system to operational status in Cy43h2.2. The highest priority was to perform parallel runs in MetCoOp, AEMET and MetEireann for evaluating several flavours of 4D-Var in combination with the physics changes in Cy43h2.2. Work has continued to optimize the computational performance of 4D-Var by means of OpenMP parallellization and the use of single precision in the trajectory run. The application of single precision in the screening is still under investigation. Studies to extend and optimize the use of observations in 4D-Var are ongoing (e.g. inclusion of GNSS, radar, and cloudy radiances). Experiments with the aim to optimize 4D-Var settings for the control vector (e.g. for the control of LBC) and extension zone are continuing. Also, a variety of 4D-Var configurations is being tested in nowcasting ensemble setups and continuous data assimilation approaches.

The next step presumably will be to move to a 3- or 4DEnVar data assimilation system. For Harmonie a hybrid 3/4DEnVar system has been developed. In parallel, Meteo-France is working on the tuning and longer-term evaluation of a 3/4D-EnVar setup under OOPS for a 2022 e-suite. Aspects like the optimal ensemble size, spatial scale-dependent localization lengths, use of full or hybrid EnVar, and spinup issues are being studied. Intercomparisons between the different methods are being done, both from a data assimilation and from an ensemble perspective.

A Harmonie 3D-Var version has been created successfully within the OOPS code framework, and is running properly with conventional data. In the coming months, this setup will be expanded with the use of non-conventional data in 3D-Var, and with 4D-Var. When this has been achieved, hopefully by the end of 2022, the next step will be the integration of the Harmonie hybrid EnVar and other (nowcasting-related) algorithmic developments in the OOPS framework.

<u>A2: Optimal use of (high-density) atmospheric observations</u>
At present, Harmonie still uses as default a 3D-Var assimilation system, which assimilates conventional data and cloud-free radiances from AMSU-A, AMSU-B, MHS and IASI. Additionally, several types of spatially and temporally dense data can be assimilated optionally: radar radial wind and reflectivity volume data, GNSS ZTD, GPS-RO, SEVIRI water vapour observations, Mode-S data, AMV's and scatterometer winds, and observations from private weather stations and smart phones. Continuous efforts are being made to monitor and then further enhance the impact of these data types, through improved data quality control, the application of more intelligent thinning or superobbing strategies, enhanced variational bias correction, and careful tuning and optimization of the observation statistics and structure functions.

Recently added satellites have improved data coverage for radiances especially in the morning.Improvements have been tested and implemented in e.g. radiance varBC updating procedures and cloud detection, in order to increase the impact of these data. Extensive experiments are being done with the aim to enhance the use of low-peaking MW channels. A first implementation has been made of an all-sky approach for the assimilation of MHS radiances in Cy46h1. Work is ongoing to fine-tune blacklisting and assess the sensitivity to e.g. model microphysics parameters. The use of the supermodding approach, initially applied to scatterometer and Aeolus data (Mile et al. 2022), has now been extended to radiances.

After promising impact studies with GNSS STD data (positive impact up to +12h), a pre- operational run is being prepared with the combined assimilation of zenith and slant total delay (ZTD and STD) data. For Mode-S data, European data coverage continues to increase, recently particularly over Scandinavia and southern Europe (see fig.1). For radar data, the temporary outage of the Baltrad server has intensified collaborative work to process and quality-control radar data from the Opera OIFS service. The aim is to develop a common, stable, high-quality ACCORD radar handling framework for both OIFS data and for the shorter-latency radar data available via Baltrad. Radar assimilation experiments with 4D-Var have shown that 4D-Var is able to improve the bias in relative humidity significantly with respect to 3D-Var. A study has started on how best to handle different sensitivities of neighbouring stations in radar reflectivity assimilation. For assimilation of radar radial winds, AEMET experiments have shown that a very careful quality control of elevation data and choice of superobbing sizes are needed.

Promising results have been obtained in studies of the assimilation of surface pressure and screen level parameters in the upper air analysis, and in an assessment of the potential use of BUFR descent radiosonde data. Work on the processing, quality control and assimilation of third-party observations from private weather stations (PWS), smart phones (SPO), wind farms and car/road observations has continued. Data and quality control procedures for both NetAtmo and WOW PWS observations have been made available for an ongoing Eumetnet intercomparison of quality control procedures for these data. DMI has set up a robust data flow for SPO data assimilation in daily runs. The code to collect and pre-process these data can be added as a module in NMS weather apps. Comparisons of the processing and assimilation impact between SPO and NetAtmo surface pressure level data are underway.

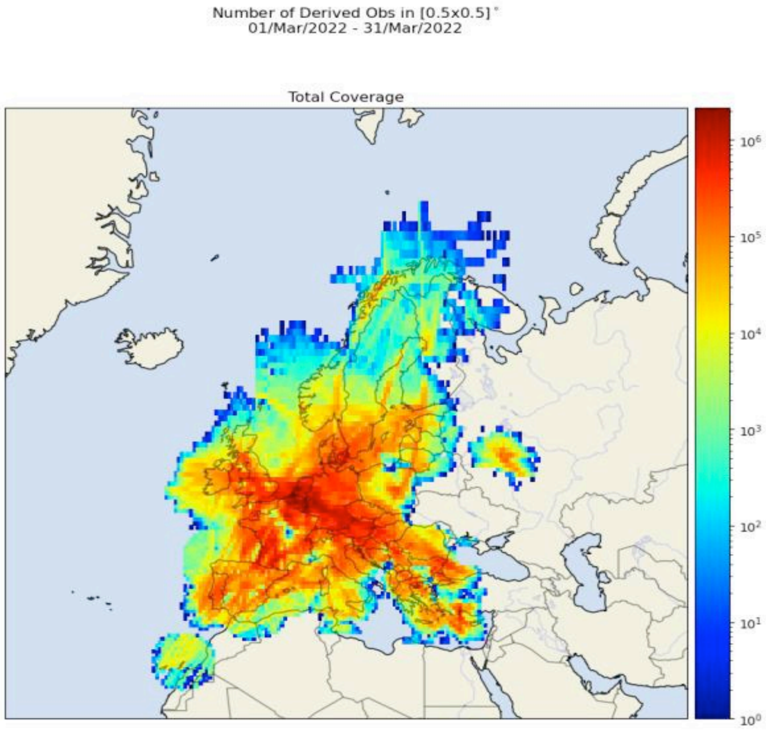

Fig. 1: The coverage of Mode-S data made available over Europe via EMADCC in March 2022. Since summer 2021, coverage over Scandinavia and central/southern Europe has increased a lot. With the introduction of improved preprocessing, also the quality of EMADCC data has been markedly improved.

A3. Optimization of data assimilation setups for the nowcasting range

For nowcasting, the focus is on moving towards sub-hourly cycling and assessing the challenges for assimilation on those timescales, particularly the issue of model spinup, in a common nowcasting branch. Technically, sub-hourly cycling has been enabled in the Harmonie code and scripts, and experimentation with it has started.

A dedicated nowcasting branch and testing plan have been set up to systematically test and intercompare different data assimilation configurations in the nowcasting range. These configurations include 3- and 4D-Var with different cycling strategies (e.g. hourly, continuous, overlapping windows) and initialization techniques aiming to reduce spinup (DFI, IAU), plus some other methods aiming to bring the model analysis closer to observations (several variants of the cloud initialization (Gregow 2017), field alignment (Geijo 2012), and variational control (Geijo 2019) techniques). Coordinated experiments are being performed to test and intercompare these configurations.

Diagnostics studies of spinup are being carried out with tools like ECHKEVO and DDH. Verification will be carried out not only for lead times but also for time of delivery. Problems with correlated observations become more pronounced at higher temporal and spatial resolution. For 4D-Var especially, temporal correlations are an issue to be tackled. For the handling of spatially correlated observations, error modelling approaches are being considered as a more sophisticated alternative to standard thinning or superobbing practices. New or improved SAF products have been suggested, and are being tested, for a better initialization of cloud characteristics and identification of multi-layer clouds.

One relevant issue is how to best take the large scales from the nesting model into account in the nowcasting range. For this, there presently are the LSMIX and Jk cost function approaches available. Ole Vignes has derived an alternative model cost term treatment, by combining nesting and nested model background into a single background cost term; first tests have shown the performance of this "mixed" cost term approach to be better for the short range (up to ~12h) in the summer, less clear results were obtained for a winter period. These investigations will be continued.

B) Atmospheric forecast model

B1. Studies to eliminate systematic model errors for clouds and fog:

A major long-standing forecast has been the prediction of fog under stable boundary conditions, especially over sea: fog generally building up too quickly, having a too large extent (especially over sea), too much cloud water, and starting a too quick and too strong cooling over sea. In the past years, this model behaviour has been shown to be critically dependent on the assumptions made in the ICE3 microphysics scheme on the density of cloud condensating nuclei. This experimentation and testing of fog-related changes in Cy43h2.2 has led to the adoption of a condensating nuclei density concentration (CNDC) vertical profile in the ICE3 microphysics, rather than assume a constant CNDC value over sea, rural and urban areas. This was done as a temporary pragmatic solution before the anticipated introduction in the coming years of near-real-time observed aerosol and (later) the second-moment microphysics scheme LIMA. The CNDC profile assumption generally does result in improved humidity and cloud base characteristics over land, but optimal values for the profile function differ between e.g. Nordic and Iberian domains. These things will need more detailed investigation.

A more definitive solution is expected from the use of the second moment scheme LIMA and the introduction of aerosol parametrizations, in combination with near-real-time aerosol initialization from CAMS. However, there are still many aspects to experiment with, and tune, this setup. Work has started on a parametrization describing the fraction of aerosols which are active in condensation. Measurements of droplet size distributions show that shallow fog has larger droplets than deeper well-developed fog, cooled from the top by turbulence. Because of this, it is being considered to make the activation of aerosols TKE and vertical velocity dependent. HIRLAM participation in the model inter-comparison experiments for the SOFOG3D IOP's may be very useful for the tuning of this aerosol activation.

Single column studies have shown that modelled fog development may be as sensitive to the assumed shape parameters of the cloud droplet size Gamma distribution (a rarely studied part of the microphysics parametrization) as it is to the underlying aerosol or cloud droplet number concentration. These sensitivities are being explored further in the context of SPP perturbations for HarmonEPS (see section D).

A long-standing weakness of the Harmonie model has been its poor representation of open cell convection features observed in clouds, and the precipitation associated with such clouds. A reduction of the too strong momentum mixing by the shallow convection scheme has led to a more realistic organization of open cell cloud structures, and the light precipitation associated with such clouds.

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

Presently, 11 types of aerosol can be retrieved from near-real-time (NRT) CAMS data. Experiments have shown that the use of this NRT information may have significant (beneficial) impact on e.g. model snowfall amounts, dust attenuation of SW radiation (see fig.2), fog and precipitation. A data flow has been developed for the consistent use of the aerosol information in the different relevant parts of the Harmonie model physics (radiation, cloud and microphysics schemes). Work has also begun to develop a parametrization describing the fraction of aerosols which are active in condensation. Measurements of droplet size distributions show that shallow fog has larger droplets than deeper well-developed fog, cooled from the top by turbulence. Because of this, it is being considered to make the activation of aerosols TKE and vertical velocity dependent. HIRLAM participation in the model inter-comparison experiments for the SOFOG3D IOP's may be very useful for the tuning of this aerosol activation. Longer-term impact studies for both near-real-time and climatological CAMS aerosol information are being carried out for several domains. The added computational cost of using NRT aerosols is ~12-24% of the present forecast model cost.

At present, these NRT aerosol experiments are still being done using the 1-moment ICE3 microphysics. When the LIMA second moment scheme will become available in Cy48h2, it will be assessed as alternative to ICE3 microphysics, but this will presumably still require considerable testing and tuning.

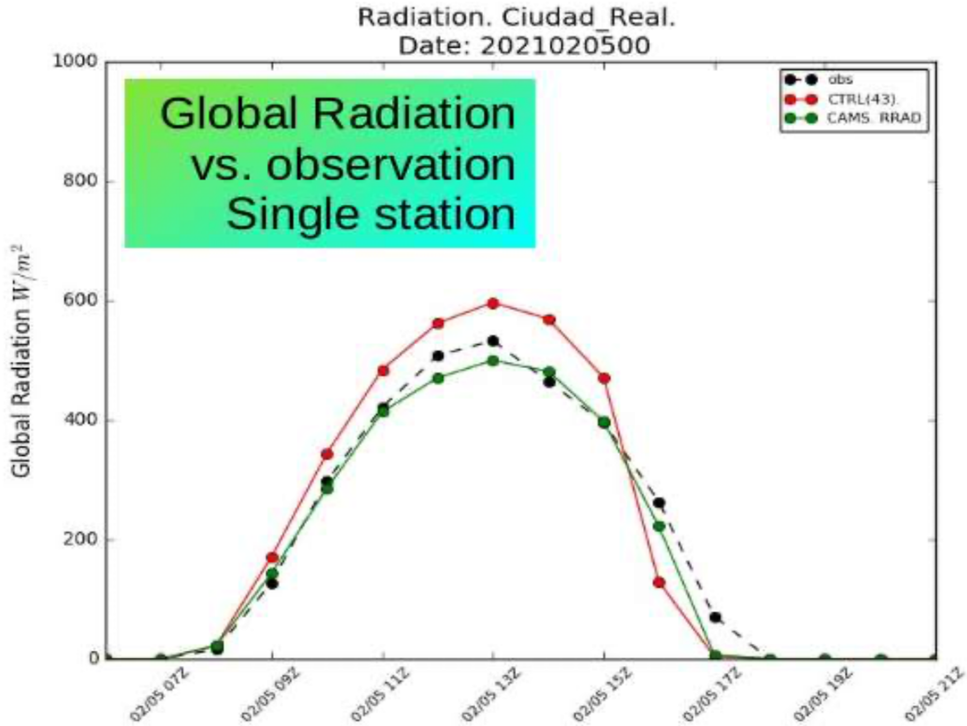

Fig. 2: Case study example of impact of use of near-real-time aerosol in the Harmonie radiation parametrization over the Iberian domain in a period of dust intrusion from the Sahara. Shown is the global radiation for observations of the Cuidad Real station (black curve), and for the Harmonie model at that location without (red curve) and with near-real-time CAMS aerosol (green curve). The impact of the radiation absorption by dust in the model can be clearly seen.

<u>B3. Sub-km resolution modelling</u>

Many HIRLAM services are experimenting by now with sub-km (150-750m) horizontal resolution model setups (e.g. Palmasson et al. 2022, Suarez-Molina and Calvo 2021, Tijhuis et al. 2022, Clancy et al. 2022). Some of these setups have reached operational status already, and gradually efforts are being extended to smaller scales, to discover the limitations which the present dynamics and physics parametrizations may have there. Some first studies have been done on how to handle the transition from parametrized to fully explicit shallow convection in this resolution range. The added value of increasing vertical resolution in these setups, and the associated need for retuning physics parametrizations to a greater number of vertical levels, is under investigation. Meteorological performance of the sub-km setups has been shown to be quite sensitive to e.g. domain size (larger domains generally having a better performance) and the treatment of the LBC coupling of hydrometeors (nesting in a model with a similar set of hydrometeors giving better results than one where the nesting model has fewer hydrometeor types). Some experiments have shown noise issues in setups with <500m resolution, and the optimal dynamics settings to handle these are under investigation.

Ideas have been developed on introducing computationally affordable (quasi-)3D physics schemes for turbulence and radiation. For radiation, DMI staff have been considering the modelling of 3D cloud shading effects on radiation in a quasi-3D approach, using the SPARTACUS solver in the ECRAD scheme in combination with machine learning. Also the possible use of process-dependent time-stepping and resolution for individual physics schemes will be considered, in the first instance for the radiation scheme (which could be used intermittently and/or at a reduced computational grid), primarily in order to reduce computational costs.

In sub-km resolution Harmonie runs, boundary layer cloud streets are often represented too strongly and smoothly. The introduction of stochastic elements in the physics parametrizations may help to disrupt the too smooth model behavior and locally trigger deep convection. Machine learning approaches have been identified with which to pursue this further.

C) Surface analysis and modelling

C1: Improving the sophistication of surface model components

In the past two years, many tests have been done with the new multi-layer diffusion soil, extended snow and snow-over-vegetation schemes (DIFF,ES, MEB) and the new SEKF assimilation scheme for soil and snow. After successful initial tests over the Arome-Arctic, this combination of schemes is now being run in an extensive set of pre-operational tests for several other European/Atlantic domains. This setup uses assimilation of screen level conventional and, over some domains, additional private weather station data. In general, the combination of new surface schemes results in an improved diurnal cycle for screen level parameter, warmer and dryer model behaviour during winter, and colder and wetter behaviour in summer. Summer. Both improvements and deteriorations are seen, depending on area and season. Problems have been seen with snow depth, and these are under detailed investigation.

Studies have continued on a more realistic treatment of the canopy layer (both vegetation and urban) in the determination of surface roughness lengths. SMHI and AEMET staff have introduced, and have begun evaluating, a vegetation roughness sublayer (RSL) scheme into the model which accounts for the effects of canopy-induced turbulent mixing (Hartman and Finnegan 2007). 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. In offline runs, the RSL scheme showed improvements mainly in momentum and nighttime heat fluxes and near-surface wind speed. In online runs, however, results were considerably more mixed. This may be due to the fact that in online runs with the RSL scheme the level z=0 starts at canopy height; this affects the model diagnostics and complicates NWP validation against screen level observations.

A new parametrization for surface fluxes over the ocean, ECUME-6, has become default in Cy43h2.2. ECUME-6 in general leads to stronger fluxes of heat and moisture than its predecessor. Overall, the switch to ECUME-6 in Cy43 leads to more accurate near-surface values and low-tropospheric profiles for temperature and humidity, a lower bias in mean sea level pressure, and somewhat more fog over both land and sea. Progress has been made in testing the performance of coupled atmosphere-ocean-wave model setups over Arctic and Irish domains, with neutral to slightly positive results. The 1D ocean model GOTM has been implemented in Surfex, to facilitate coupled atmosphere-wave-ocean-sea ice studies in the Arome-Arctic domain. Staff in Ireland are working to couple the 3D-ROMS ocean model to the already developed coupled Harmonie-WaveWatch3 wave model. SMHI and KNMI have continued work on creating and assessing the coupling of the model with local hydrological models.

C2. Enhanced use of satellite surface observations in combination with more advanced surface assimilation

The new SEKF assimilation scheme will enable the increased use of satellite surface products. The first thing to be tested in this context, is the assimilation of satellite snow extent, which has been shown to be important in the cold season in areas where SYNOP snow cover stations are sparse or missing. To avoid errors in the screening/thinning and interpolation of raw satellite data, the so-called “snow barrel” method has been developed by FMI for the assimilation of satellite snow extent data. The data flow in the Harmonie assimilation system has been adjusted to permit satellite snow extent assimilation with the barrel approach. Regular production of “snow barrel” data has started at FMI, and this is being tested further over Scandinavia. Other satellite data which are being studied for future inclusion in the surface assimilation after the SEKF introduction, are OSI-SAF sea ice surface temperatures in the sea ice assimilation, and retrievals from various satellites in lake data assimilation. Also, the dataflow is being prepared for including more satellite (ASCAT, SMOS, MODIS and H-SAF) retrievals of soil, vegetation, sea surface and inland waters properties and snow- and ice-covered surfaces progressively into the surface assimilation.

For the sea ice assimilation, use is made of a so-called bias-aware EKF, which is better able to take into account the SICE model temperature bias under certain situations. Normally, in an EKF, a bias correction is done at analysis time; but in SICE, it was seen that for “fast” variables like air temperature, a bias was very quickly regained during the model forecast. In the bias-aware EKF, the bias correction is applied incrementally during the first three hours of the model forecasts, as a flux term in the surface energy balance. The general performance of the new sea ice data assimilation scheme is being tested against independent MODIS observations.

Several activities are ongoing to explore how to move towards (strongly) coupled atmospheric-surface assimilation. One idea which is being pursued is to add an additional layer of “screen level values” to the 3D-Var control vector in the OOPS framework. Also, a technical solution has been explored to make the results of land surface DA available to atmospheric assimilation via running Surfex offline for 1 time step.

However, some issues remain to be solved when applying this method to the new many-layer surface physics. After the introduction of the SEKF soil and snow assimilation, it is intended to move stepwise towards a more advanced ensemble Kalman filter (EnKF) setup which can be used as a basis for a strongly coupled atmosphere-surface data assimilation system and the assimilation of satellite surface radiances. An initial EnKF setup has been prepared. A restructuring of the surface assimilation is planned with the aim to permit the use of various assimilation algorithms (SEKF, EKF, EnKF) independently from specific tiles and/or patches (which is presently not the case).

C3. Enhancing physiographic information

A critical aspect for surface modelling is the quality of the surface characterization (orography and physiography). Especially in the light of the ambitions to move to hectometer-scale models, there is a clear need to improve over the existing ECOCLIMAP-Second Generation global 300m resolution database by means of local high-resolution databases and/or satellite data in a consistent manner. Thoughts have been developed on a workflow by which we can make available a physiography sufficiently detailed and suitable for use in ACCORD hectometric models for European domains. The idea is to use as a starting point a set of existing land cover databases and thematic maps of O(10m) resolution for the European area, which are being regularly updated in e.g. Copernicus context. Machine learning is then used to "translate" this aggregation of maps to a higher resolution, improved physiography database for Europe, with the same labelling (set of land cover types, water bodies and urban local climate zones) as ECOCLIMAP-SG. It is aimed to create such a European scale O(10m) resolution high-quality physiographic database in the coming years, as a powerful tool for hectometer-scale modelling in Europe.

This database may also turn out to be useful for tackling a well-known and long-standing problem in all NWP models, namely the treatment of very stable boundary layer (VSBL) conditions. In the VSBL, the assumptions of horizontal homogeneity underlying NWP turbulence schemes are probably invalid, and the details of actual surface heterogeneity will have a crucial impact on surface fluxes. The planned database should help to provide those details and is intended to be used in VSBL studies.

D) Probabilistic forecasting

In the EPS area, work has continued to focus on including model perturbations using SPP into operational ensembles. A paper describing the SPP work has been published in MWR. A set of 11 parameters has been identified earlier to have some appreciable impact on ensemble spread. As shown by the URANIE VVUQ tool, a large fraction of this impact is provided by a subset of 5 parameters, which is now being used to get SPP into operations soon. Experiments have been done for each parameter with alternative parameter pdf distributions (uniform and shifted uniform vs the default lognormal distribution), and for studying the behaviour of correlated parameters. For some parameters, ensemble spread, skill and bias behaviour have been shown to be quite sensitive to the assumed pdf distributions, particularly for cloud-related parameters (see fig.3 below). Initial experiments using the same perturbation pattern for two correlated parameters resulted in less bias and better spread. Also, attempts are being made to reduce the computational cost of SPP, e.g. by applying SPP only every hour instead of every time step. The cost increase of 15% which was found after the first introduction of SPP can be reduced to +3% by calling the perturbation pattern less frequently. In the near future, testing will start of using SPP in single precision in Cy43h2.2.

Several new mass flux related parameters have been identified in the shallow convection scheme which affect the intensity of moist and dry updrafts. Experiments with these parameters over several seasons show appreciable impact during summer convective periods, moderately increasing ensemble spread for near-surface and cloud parameters and some improvements in CRPS, FSS and RMSE, without any systematic ensemble bias issues. Some parameters related to the shape of particle size distributions in the microphysics are still being experimented with. A start will be made with testing perturbations of hydrometeor fall velocities.

Earlier, it was shown that the systematic drying which occurred in ensemble members with respect to the control run could be attributed to surface soil wetness perturbations which were insufficiently constrained in cases where the soil moisture in reality was above field capacity or below the wilting point. Modified versions of the surface perturbations are being studied, which force soil wetness perturbations to remain well between wilting point WP and field capacity FC. Simple clipping approaches have been shown to be inadequate to eliminate the dry bias problem.

Work is ongoing to study the impact of computing perturbed ensemble forecasts in single precision (SP), while keeping the control run in double precision (DP). SP ensemble member forecasts were ~30-40% faster than DP runs. Tests on model stability and meteorological performance are being performed over several domains, initially in Reading but now switching over to the AA system in Bologna. If the random number generation for the pattern generator is done in 64 bits, the SPP perturbation patterns in single and double precision are found to be reproducible. Meteorological differences between SP and DP forecasts for a single member appeared to be quite small compared to differences between individual perturbed members, and SP and DP runs generally performed equally well in terms of meteorological scores.

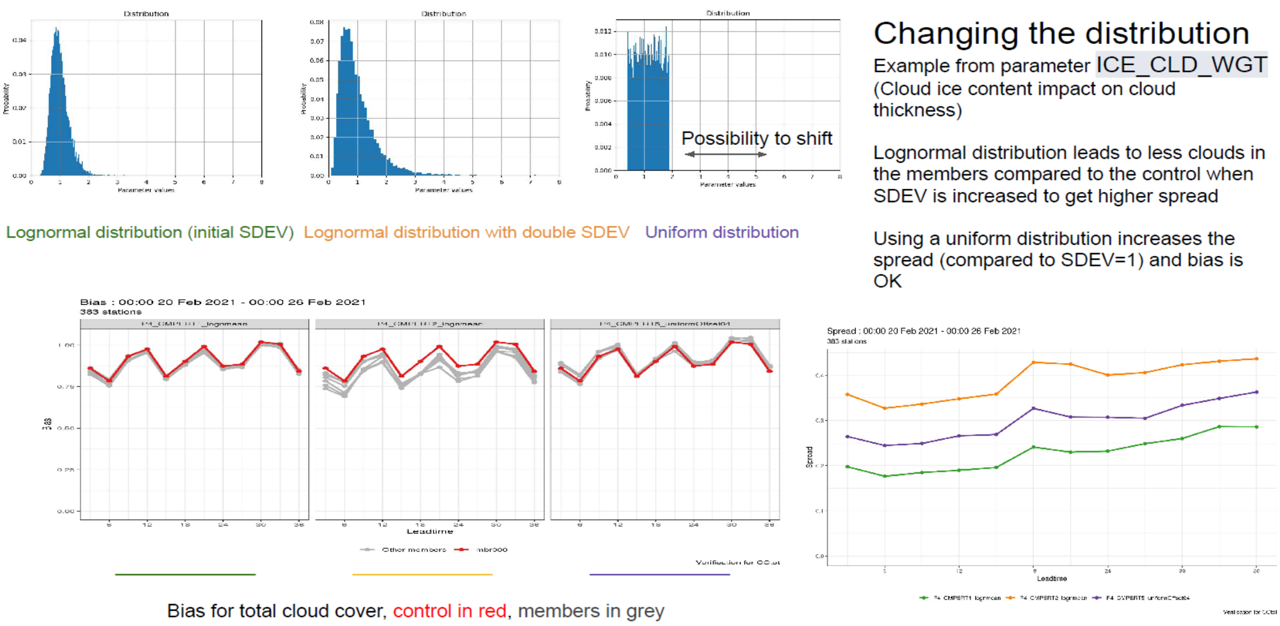

Fig. 3: Experiment showing the impact of changing the shape of the assumed distribution of a cloud ice-related model parameter used in HarmonEPS SPP perturbations. The left upper figure shows the standard lognormal distribution assumed in SPP. The middle upper figure a lognormal distribution with the twice the standard deviation of the standard one, in order to enhance ensemble spread (orange vs green curve in the lower right figure). However, this also introduces a bias of ensemble members with respect to the control (middle frame in lower left figure). The top right figure presents a uniform distribution, which can be shifted if required. This enhances ensemble spread with respect to the lognormal distributions (blue vs green curve in lower right figure) but does not affect the ensemble bias with respect to the control (right frame of the lower left picture).

E) Computational efficiency, portability and system aspects

Various tests have been carried out for Harmonie-Arome in single vs double and mixed precision, not just for the forecast model but also for the various parts of 3- and 4D-Var data assimilation and ensemble systems, see sections A and D above. For 4D-Var, some problems remain with using SP in the minimization. When going from double to mixed precision, typical runtime reductions of ~35-40% are found.

In collaboration with ECMWF, staff at DMI have been working on improving the computational efficiency of a part of the ECRAD radiation scheme by ~40%, using machine learning (ML). This will be implemented and tested in Harmonie-Arome as well. This type of emulation by ML will be extended to other parametrizations (turbulence, quasi-3D radiation, microphysics) in the future. In addition, the potential of ML for optimizing parameters will be further explored. Other applications of ML in which activities have started up or have become more refined, are in the quality control of crowd-sourced observations, ensemble calibration, the derivation of observation operators, and the construction of improved physiographic data.

The Harmonie system team has implemented the Harmonie Reference System on the new Bologna HPC and is preparing and optimizing the system setup in Bologna for use by the Harmonie researchers. The Harmonie testbed (for the technical validation of code changes in the Harmonie github repository) is being transferred to Bologna as well. In the future, it is intended to make regular use in this testbed of the open-source computational performance monitoring tools made by the Barcelona Supercomputing Center. HIRLAM staff have recently received a training by BSC staff in the use of these tools.

Given the increasing heterogeneity of HPC architectures, it is important to regularly establish model performance on a range of different architectures. A “containerized” version of the model has been made to permit easier porting to such alternative platforms for benchmarking purposes. Kernels are being developed for different smaller parts of the model, to facilitate the faster detection and localization of computational performance problems and easier porting of code components, e.g. to university partners. In the context of the procurement of a new HPC for the joint operational use of the services of DMI, IMO, KNMI and Met Eireann, benchmarks have been performed on a variety of systems involving CPU, GPU, AMD, ARM and mixed architectures.

On the short term, an OpenAcc directive approach is being used in order to make the ACCORD LAM forecast models, including Harmonie-Arome, ready for use on GPU and mixed CPU-GPU architectures. In 2022, the main goal is to refactor the forecast model Fortran code, in preparation for near-automated hardware-specific code adaptation to permit effective use of the model on alternative architectures. This refactoring is similar to the one which is done for the data assimilation code in the context of OOPS (see section A). Meteo-France staff have created a refactored prototype code for Arome-France. This prototype has become sufficiently mature for Harmonie staff to carry out and validate a refactoring of the Harmonie forecast model codes along very similar lines. These efforts, which should be largely concluded before the end of 2022, also will permit a large cleanup of the main forecast model steering routines, and to achieve a greater interoperability between the Arome-France, Harmonie and ALARO forecast models at the level of individual parametrizations schemes.

After the Fortran code refactoring, the second step is to adapt the Fortran code largely automatically for use on other HPC architectures. This is done in different ways for different parts of the code. For spectral transforms, hardware-optimized external libraries and API's will be used like the ECTRANS library developed by ECMWF. In the case that machine learning emulation algorithms are introduced into the model, similar external libraries already exist. For grid point calculations, we rely on semi-automatic code transformation tools (LOKI, fxtrans) to generate hardware-specific code through e.g. loop re-ordering and memory layout. The application of these tools for making the refactored ACCORD LAM codes ready for use in GPU or mixed CPU-GPU architectures will be a main priority for 2023.