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 Jan. 2019 – June 2019

Project Title: HIRLAM-C 2d phase (2019-2020) 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 2019

Expected end date: 31 December 2020

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)			32 MSBU	2.8 MSBU (by 17 June)
Data storage capacity	(Gbytes)			20.000	20.000

Summary of project objectives (10 lines max)

The main areas of attention are:

- increasing the range and impact of high-resolution and remote sensing data to be assimilated (esp. all-sky radiances, OPERA radar data, crowd-sourced observations and satellite surface observations)
- introduction and optimization of flow-dependent assimilation techniques (4D-Var, 3/4DEnVar)
- improvement of the model behaviour for low clouds, fog and stable boundary layer conditions
- a more sophisticated and consistent description of the radiation-cloud-microphysics-aerosol interaction and winter stable boundary layer conditions
- a more sophisticated surface analysis and modelling system.
- definition of and experimentation with sub-km resolution nowcasting (ensemble) setups

Summary of problems encountered (10 lines max)

No problems worth mentioning. Excellent support from ECMWF as usual.

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

In the period until end 2020, the main priorities will be:

- bringing major developments like 4D-Var and the overhaul of the surface analysis and modelling system to operational status
- improved forecast model behaviour for fog and low clouds,
- the continued development of ensemble assimilation techniques
- the development and introduction of high-resolution nowcasting ensemble setups
- increased use of crowd-sourced and satellite surface observations
- and achieving enhanced computational efficiency and scalability.

List of publications/reports from the project with complete references

- Aspelien, T., et al., 2018: "On the use of amateur weather stations in an operational nowcasting and NWP framework", ALADIN-HIRLAM Newsletter 11, p.31-34, http://www.umr-cnrm.fr/aladin/meshtml/nl11.pdf
- Bakker, K., K. Whan, W. Knap, and M. Schmeits, 2019: Comparison of statistical post-processing methods for probabilistic NWP forecasts of solar radiation. *Solar Energy, submitted.*
- Frogner et al., 2019, "HarmonEPS: the Harmonie ensemble forecasting system". Weather and Forecasting, under revision.
- Geijo, C., and P. Escriba, 2018: "Variational constraints for data assimilation in the ALADIN NH dynamics", ALADIN-HIRLAM Newsl.11, p.13-26 http://www.umr-cnrm.fr/aladin/meshtml/nl1.pdf
- Gregow, E., 2017, "Harmonie – MSG cloud data assimilation experiments", ALADIN-HIRLAM Newsl. 9, p 22-29. http://www.umr-cnrm.fr/aladin/meshtml/NL9-final.pdf
- Gustafsson, N., et al., 2018. "Survey of data assimilation methods for convective-scale numerical weather prediction at operational centers", QJRMS, doi:10.1002/qj.3179
- Hintzen et al., 2019: "Collecting and utilising crowdsourced data for numerical weather prediction: Propositions from the meeting held in Copenhagen, 4-5 December 2018", Journ. Atm. Sci Letters, https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/asl.921
- Huang, W., Cheng, B., Zhang, J., Zhang, Z., Vihma, T., Li, Z., and Niu, F.: Modeling experiments on seasonal lake ice mass and energy balance in the Qinghai–Tibet Plateau: a case study, Hydrol. Earth Syst. Sci., 23, 2173-2186, https://doi.org/10.5194/hess-23-2173-2019, 2019.
- Køltzow, M., B. Casati, E. Bazile, T. Haiden, and T. Valkonen, 2019: "A NWP model inter-comparison of surface weather parameters in the European Arctic during the Year of Polar Prediction Special Observing Period Northern Hemisphere 1". Wea. Forecasting, https://doi.org/10.1175/WAF-D-19-0003.1
- Martin-Perez, D., 2018: "Use of CAMS aerosols to modify cloud condensation nuclei in Harmonie-Arome", ALADIN-HIRLAM Newsl. 11, p.41-46, http://www.umr-cnrm.fr/aladin/meshtml/nl11.pdf
- Renfrew, I., et al. 2019: "The Iceland - Greenland Seas Project", BAMS, in print
- Randriamampianina, R., Schyberg, H., Mile, M., 2019: "Observing System Experiments with an Arctic Mesoscale Numerical Weather Prediction Model. Remote Sens. 2019, 11(8), 981; https://doi.org/10.3390/rs11080981
  Santos, I., et al., 2018: "Verification of Harmonie-Arome model at 1.0 km over Spanish harbour areas", ALADIN-HIRLAM Newsl. 11, p. 77-87, http://www.umr-cnrm.fr/aladin/meshtml/nl11.pdf
- Schmith, T., Nielsen, J. W., Rasmussen, T. A. S., and Feddersen, H., 2018: "Better Baltic Sea wave forecasts: improving resolution or introducing ensembles?", Ocean Sci., 14, 1435-1447, https://doi.org/10.5194/os-14-1435-2018.
- Whan, K., and M. Schmeits, 2018: Comparing area-probability forecasts of (extreme) local precipitation using parametric and machine learning statistical post-processing methods. Mon.Wea. Rev., doi:10.1175/MWR-D-17-0290.1.
- Yang, X., 2019. "TAS – An operational forecast model at hectometric scale", ALADIN-HIRLAM Newsletter 12, pp.42-49. http://www.umr-cnrm.fr/aladin/meshtml/nl12.pdf

Summary of results of the current year (from January 2019 to June 2019)

The HIRLAM-C research programme (January 2016 - December 2020) is a research cooperation of the national meteorological institutes of Denmark, Estonia, Finland, Iceland, Ireland, Lithuania, Netherlands, Norway, Spain and Sweden, with Meteo-France as associated member. Within HIRLAM-C, research efforts are focussed on the development, implementation and further improvement of the mesoscale analysis and forecast system Harmonie, and its associated ensemble prediction system HarmonEPS. A Harmonie Reference system is being maintained on the ECMWF HPC platform. The computational resources for the HIRLAM-C Special Project at ECMWF are primarily used for experimentation with, and evaluation of the performance of, newly developed elements for this Reference System. Below, the main R&D and testing activities in the fields of data assimilation, the atmospheric forecast model, surface analysis and modelling, ensemble forecasting and code efficiency during the past year are outlined. From the summer of 2019 until early 2020, a large amount of testing efforts (and most of the special project resources for 2019) at ECMWF will be devoted to the assessment of many new model components in Harmonie-Arome Cy43h2.

A) Data assimilation

A1: Optimal use of (high-density) atmospheric observations:

At present, Harmonie 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, SEVIRI water vapour observations, Mode-S data, AMV's and scatterometer winds. All these data types have shown positive impact after continuous efforts on improved data quality control, the application of more intelligent thinning or super-obbing strategies,enhanced variational bias correction, and careful tuning and optimization of the observation statistics and structure functions.

This year, steps have been undertaken to improve and homogenize the preprocessing of conventional, radar and radiance observations, and blacklisting procedures have been revisited. Activities are ongoing to assess the ability of (and possible need for adaptations in) the Scalable Acquisition and Prep-Processing (SAPP) system to handle a wider range of observations (e.g. radar, Mode-S, crowd-sourced data). For radiances, options to use more low-peaking channels and emissivity atlases channels have been considered. A more homogeneous way of handling OPERA data is needed to permit use of radar data from a wider range of countries. When this is done carefully, making use of more radars is generally beneficial. However, impact studies for reflectivity volume data from increased numbers of radars beyond national borders have also shown that the joint assimilation of data from radars with significant differences in sensitivity can give negative impact. It is aimed to start monitoring individual radars to be able to account properly for these differences in sensitivity. For radial wind data, it is important to exclude radars with low Nyquist velocities from the assimilation, to avoid problems with de-aliasing.

Preparations are being made for the assimilation of radiances from Metop-C and FY-3C, including the tuning of VarBC coefficients. Cal/val activities have been, and are being, done for the Metop-C, HY-2B and CFOSAT scatterometer winds, and preparations have been made for the assimilation of real-time Aeolus Horizontal Line of Sight (HLOS) wind observations in Harmonie. The quality of the Metop-C, HY2B and HLOS winds appear to be quite good. For CFOSAT data, more cal/val works still remains to be done.

AEMET has seen beneficial impact from assimilation of AMDAR humidity data. The first tests of applying active VarBC to aircraft observations (so far with an offset only) have shown very promising results. These tests are being extended with experiments using a larger variety of VarBC predictors. The option of assimilating slant delays has been introduced for 3- and 4D-Var, together with VarBC; next steps will be the performance of longer impact experiments and the optimization of varBC predictors.

Increasingly efforts are being put on the acquisition, quality control and assimilation of observations from non-meteorological networks. Several HIRLAM services have gained experience with the quality control and use of observations from private weather stations (e.g. NetAtmo). When properly quality-controlled, these data can provide a very valuable addition to national meteorological networks due to their greater spatial density. Experience is also being gained with the quality control and assimilation of pressure tendency observations from mobile phones. These data can be especially valuable in very high resolution (sub-km) models and over urban areas. Assimilation of observations from road authority networks has shown good impact. Experiments have started with the use of boundary layer observations from offshore wind farms. In December 2018, a workshop on crowd-sourced observations was held at DMI, with the aim to build a community of developers active in this area (Hintzen et al. 2019).

The CARRA project (Copernicus Arctic Regional Re-Analysis) has provided an improved re-analysis setup for the Arctic region, with a significantly enhanced set of local surface and satellite observations, improvements in the forecast model and surface handling of glacier snow, a more realistic orography and albedo, and experimentation with several options aimed at improving the standard 3D-Var setup: EDA with observational or random B-matrix perturbations, large scale mixing through a Jk operator, and use of the Incremental Analysis Update scheme for initialization. This study is being done with 3D-Var initially, but can later be repeated for 4D-Var.

A2: Development, operationalization and optimization of flow-dependent data assimilation methods.
There are two main objectives in this area: prepare 4D-Var for operational use, and, for the longer term, continue the development and start deployment of (hybrid) ensemble assimilation methods.

In the first half of HIRLAM-C, a 4D-Var system has been implemented. In the past year, this system has been tested extensively in the short and nowcasting range. It has been extended with the option of multiple outer loops, and has been enabled to work with the full variety of observations which can be used also in 3D-Var. Longer-period runs to inter-compare 3D- and 4D-Var are being done with different combinations of high-resolution observations, as well as some in-depth case studies. These tests show that 4D-Var is able to use more observations in the minimization. Its performance with only conventional data is better than 3D-Var, but somewhat worse when GNSS and radiances are added, so there is still some optimization to be done here. The option has been introduced to run 4D-Var with a larger extension zone than the present default (11 gridpoints), as this was seen to be beneficial for the representation of horizontal error correlations. Tests of 4D-Var with different extension zones are ongoing. With conventional data only, 4D-Var is not yet able to outperform 3D-Var in the nowcasting range. A longer run with 4D-VAR and various types of high-frequency observations is being performed with the aim of assessing the impact of 4D-Var's flow-dependency on model spinup in the 0 - +2h range. Later, it is intended to test 4D-Var also at high (750m) resolution. The MPI parallellization of the code has been improved. Efforts on a more effective OpenMP parallellization are ongoing.

On a longer term, an ensemble assimilation system is envisaged. Two alternative ensemble assimilation methods, an LETKF and a hybrid EnVar system, have been developed for this and introduced as options for experimentation. The EnVar system can make use both of observation perturbations and of perturbations in the B-matrix (so-called B_{rand} perturbations). For LETKF, longer inter-comparison experiments against operational 3D-Var are ongoing, with mostly positive results so far. Preliminary results for a short period look promising for hybrid EnVar with both LETKF and B_{rand} perturbations, but this work needs further elaboration. A clean inter-comparison setup has been made to test hybrid EnVar/B_{rand} and LETKF against each other and against standard 3D- and 4D-Var. Such inter-comparison studies have recently started and will continue for the coming year.

A3. Optimization of data assimilation setups for the nowcasting range
For nowcasting, one would like to assimilate the latest observations fast and frequently. However, limits are put on this by model spinup in the first hour or two of the forecast. Above, the experiments to test whether 4D-Var may be better able to handle spinup have already been mentioned. To enhance performance of 3D-Var in the nowcasting range, several cycling and initialization strategies which should give greater weight to the most recent observations, have been tested with success: e.g. the rapid refresh approach, and the continuous or overlapping window cycling strategy (Yang, 2018), which permits efficient use of the most recent observations in an ensemble in combination with relatively long assimilation windows. The aim is to use this continuous cycling to achieve HarmonEPS nowcasting ensembles. For example, DMI is testing a setup consisting of a set of six parallel suites with base times which are consecutively shifted by 10 minutes, and with hourly or 2-hourly assimilation cycling of frequently available observations like radar (fig.2).

At high spatial and temporal resolutions, it becomes increasingly important for the analysis system to be able to correct for position and phase errors of fine-scale atmospheric features. Present variational methods are not well versed in handling such non-additive errors. In earlier years, the field alignment (FA) method has been developed, by which displacement errors of e.g. the modelled precipitation or wind field with respect to radar data can be identified and corrected before 3D-Var takes place. FA is mainly beneficial in the nowcasting range. To reduce the problems of model imbalance in the nowcasting range, a new initialization formulation has been developed. This so-called variational constraints (VC) method (Geijo and

Escriba, 2018) aims to achieve a better handling of analysis increments and a faster balancing of the model. The VC method is being tested in both 3D-Var and the LETKF system, with and without FA.

A good description of the 3D structure of clouds is an essential ingredient for nowcasting. The cloud initialization (CI) method was developed to permit a more sophisticated use of NWC SAF cloud products (cloud type, mask and microphysics) from MSG and polar satellites to adjust 3D humidity in model analyses and nowcasts (Gregow, 2017). The main challenge for CI is to have an accurate determination of cloud base. This has gradually improved, and consequently CI is now being evaluated in pre-operational mode.

B) Atmospheric forecast model

B1. Studies to eliminate systematic model errors for clouds and boundary layer behaviour:

In the past years, problems were reported with the timely initiation of deep convection, the description of stratiform precipitation and open cell convection, too persistent fog in the model, a negative cloud frequency bias and a too high model cloud base in fog situations. Coordinated experimentation has been performed to understand the (multiple) causes of the observed model behaviour for convection and low clouds.

One cause of problems with the model triggering convection too little and too late has turned out to be the unrealistic description of climatological evapotranspiration in ECOCLIMAP2.2, in combination with a too strong impact of the surface assimilation. As an interim solution, a configuration in which both the LAI and the size of the surface assimilation increments have been reduced for the growing season is undergoing testing. Also, the impact of an improved physiographic database, ECOCLIMAP-SG, is being assessed. A more definitive solution is expected from the introduction in early 2020 of a more sophisticated surface soil model, in combination with the new soil assimilation scheme and ECOCLIMAP-SG (see section C).

The initiation of supercell formation in the early evening sometimes does not happen with the present HARATU turbulence scheme. This appears to be caused by too much dry air being mixed by HARATU from above into the boundary layer, which may then have become too dry to permit convective initiation. A first set of changes in the cloud and turbulence schemes resulted in some improvements: a more realistic transport of humidity and TKE from sub-cloud to cloud layers and a better daily cycle for humidity and clouds. These changes also had some positive effect on the model tendency to over-predict low clouds and producing a too high cloud base in cases of fog, but overall they were still insufficient to fully address the observed model weaknesses. A second set of updates involved changes in the free atmospheric length scale, several adaptations affecting the mixing of momentum and moisture near inversions, and adjustments to the statistical cloud scheme. First results of experiments with these updates indicate a strong and positive impact on both the representation of deep convection and of low clouds.

A third weak point is the balance between "cold" and "warm" hydrometeors in mixed-phase clouds and the way in which they interact with the development of convection. In both 1D and 3D experiments, it was shown that the ICE3 microphysics scheme lets far too much solid precipitation form in the form of graupel and too little in snow. This may lead to an underestimation of cold pool formation. In initial experiments with the Thompson microphysics scheme as compared to ICE3, the Thompson scheme was shown to lead to more super-cooled liquid water and less ice, and more production of snow and freezing drizzle. It provides a more realistic description for the stratiform precipitation which is formed from the dispersion of the anvil in the dying-out phase of the deep convection life cycle. The lack of snow produced by the present microphysics may also be an underlying cause of the model's inability to represent open cell shallow convection; this appears to be better represented when elements of the Thompson microphysics scheme are implemented into the ICE3 scheme. However, more extensive experimentation and inter-comparisons will be needed to achieve firm conclusions on these two aspects.

Another long-standing problem has been the underestimation of temperature minima at night during very stable boundary layer conditions. This behaviour is very sensitive to the value adopted for the maximum Richardson number. In recent experiments over Scandinavia temperature minima under very stable conditions strongly improved when using higher values of this parameter than the present default; however some deteriorating scores have also been seen for other variables, so this needs to be studied further. Also, the impact of adapting the maximum Richardson number on fog still remains to be investigated more deeply.

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

The harmonization of the microphysics and radiation schemes in terms of e.g. sub-grid scale assumptions on different water species, cloud condensation nuclei, and cloud overlap assumptions, is progressing. Work has continued on studying the benefits of climatological and real-time aerosol information from CAMS on clouds and radiation. Experiments are being carried out with cloud-aerosol interaction parametrizations for individual aerosol types, using prescribed daily CAMS global aerosol fields to update the 3D number of cloud droplets Nc. In a first CAMS aerosol test configuration, parametrizations were incorporated for dust by ALADIN, and for sea salt and sulphate by HIRLAM, as these aerosol types are believed to be the most important ones for the cloud-aerosol interaction. One-month long runs for the spring and summer season has shown this first setup to result in neutral headline scores but slightly better results for extreme precipitation over Iberia. In a second configuration, two additional aerosol types (hydrophylic organic material and black carbon) were added, and aerosol wet deposition was included. These additions give rise to increased aerosol CCN concentrations, especially over land and in the lower troposphere. This could be relevant for fog formation. Several case studies on the impact of observed aerosol on e.g. fog and precipitation have produced mixed results. CAMS mixing ratio fields have been used to calculate the vertical distribution of aerosol optical depth. In a dust intrusion case, it was shown that use of this real-time CAMS AOD in the model radiation scheme resulted in much more accurate downward short-wave radiative flux and T2m during daytime than the climatological AOD.

B3. High (sub-km) resolution modelling

At present, the Harmonie forecast system is generally operationally run at 2.5km horizontal resolution and with 65 layers in the vertical. Local efforts to investigate and optimize model performance at higher (sub-km) horizontal and vertical resolution are ongoing in many HIRLAM services. Work has progressed to assess optimal dynamical settings for numerically stable setups (e.g. testing different time stepping schemes, a vertical resolution increase, cubic vs linear grid, model behaviour near steep orography, and the behaviour of gravity waves). Verification over more than 1 year for the Greenland 750m resolution domains shows the robust added value of the these setups (fig.1). A 750m resolution ensemble nowcasting setup has been created for Denmark for which various data assimilation setups and cycling strategies have been investigated. The best results were obtained with a combination of 6 partially connected sub-ensembles, each with a not too short cycling period to minimize spinup problems (fig.2). Ways are being examined to derive improved hybrid structure functions for sub-km domains. Work is also starting on physics parametrizations, surface modeling, and computational performance aspects. A critical aspect for all partners is the quality of the surface characterization (orography and physiography), and the need to optimize this using local high-resolution databases. It will require a significant effort to do this consistently across European borders.

C) Surface analysis and modelling

C1. Enhanced use of satellite surface observations in combination with more advanced surface assimilation

One of the main objectives in HIRLAM-C is to enhance the very unsophisticated OI surface analysis system through the introduction of more advanced assimilation methods in combination with a wider range of satellite surface observations. The aim for 2019 is to replace the OI system by a set of simplified extended Kalman Filters (SEKF's) for soil, snow, and sea ice, in combination initially with conventional near-surface observations, and with the new diffusion soil and extended snow schemes. In-line and offline SEKF setups have been or are being prepared for this. In parallel, some research efforts have focused on the exploration and development of more powerful envisaged future assimilation methods such as EnKF and particle filters.

Verification of the SEKF performance versus that of the present OI is done using both CANARI and the newer TITAN/gridpp scheme for horizontal spatialization, to test the suitability of TITAN/gridpp as a successor to CANARI. Advantages of TITAN/gridpp are its more modern code base, and its proven ability to handle non-standard observations such as data from amateur weather stations. The TITAN/gridpp code has been made available in the Harmonie Reference at ECMWF for assessment by a wider community.

For the soil SEKF, several aspects are still under study, such as a new set of control variables and the possible need to avoid assimilation of soil variables under certain conditions, e.g. during rain events. In combination with the new ISBA-DIF diffusion soil scheme, the behaviour of the Jacobians in the soil SEKF was observed to be far more stable than in the SEKF in combination with the old Force-Restore scheme. The SEKF for snow is presently limited to only two of the prognostic variables of the Extended Snow scheme, snow extent and snow water equivalent; the assimilation of other prognostic variables may be considered for the future. Experiments with assimilating a variety of snow products from e.g. H-SAF are underway. Snow extent assimilation was seen to give improvements especially over the snow melt period. Inconsistencies were found between the land-sea mask as used in the Surfex physiography and that of the CANARI system used in the horizontal spatialization. These inconsistencies were quite damaging for the snow analysis. Work is ongoing to remove these inconsistencies, by using land fraction information in addition to the land-sea mask in CANARI.

From 2020 onwards, lake assimilation will be included and satellite retrievals of soil, vegetation, sea surface and inland waters properties and snow- and ice-covered surfaces will be added progressively to the surface assimilation. These include ASCAT and SMOS products for soil moisture and vegetation, MODIS lake water temperature and ice fraction, and H-SAF and MODIS products for sea ice surface temperature and snow extent and depth. Impact studies for most of these products have already been performed or are ongoing. Also, the sensitivity of the surface analysis to e.g. settings for cycling and assimilation window lengths will be checked. Beyond 2020, raw satellite radiances and Sentinel-S SAR data will be included in the analysis of soil moisture, soil temperature and snow, and more sophisticated assimilation schemes such as EnKF will be tested as successor of the SEKF's. For experimentation, an EnKF is already being run with AMSR-2 and SMOS radiance observations.

C2: Improving the sophistication of surface model components

For surface modelling, the main focus has continued to be on improving the description of Northern, Arctic and Antarctic conditions in Harmonie. Key issues have been the handling of snow, ice, forest, lakes and sea ice. Recent updates in the sea ice and lake models (SICE, FLAKE) and an orographic parametrization for turbulence, OROTUR, have been or are being implemented in Cy43h2. The introduction of prognostic ice thickness and of snow over ice in the new SICE model have been shown to reduce the warm ice temperature bias seen in the original scheme, and the new version compares better to MODIS IST observations. Experiments with OROTUR are ongoing over various domains. A significant improvement in wind bias in mountainous areas was seen over Iberia, less conclusive results were obtained over other domains.

This year, the testing has begun of the combination of several new, more sophisticated modules for soil (the diffusion soil scheme DIF), snow (Extended Snow (ES) scheme), and snow-over-vegetation (Mass Energy Budget (MEB) scheme) . The individual schemes each have shown good potential already. The combined testing is being done in both NWP and in climate mode, the latter in order to assess to what extent the new schemes may suffer from systematic biases. A four-year climate simulation run has been done for the new set of schemes together with ECOCLIMAP2.2 for Iberia; this is being analysed, and an assessment is being made of soil spinup. The European network of surface flux sites is used to validate surface fluxes. A similar run will be done also with the new physiographic database ECOCLIMAP-SG, as this has been shown to have very significant differences with respect to its predecessor (see below).

A modified version of the ES snow scheme is being developed for improved treatment of glaciers. A new method has been introduced to use satellite albedo over glacier areas, which is far more realistic than ECOCLIMAP climatology. A parametrization describing the creation of turbulent wakes in and behind wind farms over sea, using a method described by Fitch et al. (2012), has been introduced and is being validated against floating lidar and platform observations.

The ECOCLIMAP2.2 physiographic database has been updated for Greenland with improvements for coast lines, glacier extents and lakes. New lake maps for Greenland have been included in the Global Lake Database GLDB. The new Soilgrids sand/clay database will be tested for default use in Cy43h2.

In 2018 a new version of ECOCLIMAP, ECOCLIMAP-Second Generation, has become available, which contains physiographic information which has been more directly obtained from satellite observations. An investigation of ECOCLIMAP-SG as compared to version 2.2 has been started for a variety of European domains. In general, ECOCLIMAP-SG, with its higher spatial detail, appears to give a better description of e.g. coastal and urban areas. The ECOCLIMAP-SG yearly cycle of evapotranspiration by vegetation clearly seems much more realistic than that of version 2.2. More detailed sensitivity tests are ongoing.

C3: Coupled atmosphere – sea surface modelling

Several HIRLAM services have continued work on the coupling of Harmonie-Arome with ocean and sea wave models by means of an OASIS-type coupler. Staff at Met Norway and SMHI have realized a coupling of Harmonie-Arome with the sea wave models WAM and Wavewatch-3. A new researcher at MetEireann will pick up work on these efforts.

D) Probabilistic forecasting:

Work has continued on assessing a variety of perturbation methods in model physics, surface, initial and boundary conditions for HarmonEPS. For physics perturbations, it has been decided to use the SPG pattern generator (Tsyrulnikov 2017) for both the SPPT scheme for perturbing tendencies and the SPP method for perturbing physics parameters. SPPT experiments have focussed on the sensitivity of SPPT perturbations to the spatial and temporal scales used in the pattern generator. Relatively small spatial scales work best, while the sensitivity to temporal scales appears to be less. For SPP, 12 physical parameters (7 related to clouds and microphysics, 2 for radiation and 3 for turbulence) have been introduced and tested. Sensitivity was seen to all but one of them. Adding the total set of SPP perturbations results in a similar skill and higher spread for most model quantities, apart from total cloud cover where both spread and skill are enhanced. At present, SPP appears to perform slightly better than SPPT, but there are indications that we may gain from using SPPT and SPP together. Presently, all SPP perturbations are created with the same spatial and temporal scales. This is obviously unrealistic, and the next step will be to vary spatial and temporal scales for different parametrizations. A list of several more parameters for SPP has been drawn up which will be implemented and tested as well. As a new diagnostics tool, tendencies can now be derived for individual parametrizations.

Studies of perturbations of surface fields like SST, soil moisture and LAI are ongoing. Generally, these experiments lead to improved spread for T2m and RH2m, but have little impact on other quantities.

Positive results were achieved by the use of initial conditions perturbations made with EDA in combination with high resolution observations, and EDA has now become the default mechanism for such perturbations. In the coming year, more detailed inter-comparisons will be made of the performance of the three mechanisms available for generating initial condition perturbations: EDA, LETKF and hybrid EnVar/Brand. A setup has been prepared by which a clean comparison between these schemes can be made. At DMI, the continuous cycling approach has enabled the production of a larger ensemble through a more effective use of the DMI HPC, as well as earlier delivery of ensemble products and less jumpiness between ensemble runs. MetCoop has tested the continuous cycling method also for its MEPS ensemble. This setup allows to double the number of MEPS ensemble members, with similar headline verification scores.

An option has been introduced to scale ENS lateral boundary perturbations to HarmonEPS by a total energy norm. This scaling generally results in increased spread, and for some parameters in smaller RMSE.

A paper giving a scientific description of the HarmonEPS system, its various implementations and its options in detail, is under review for publication. This HarmonEPS paper complements the scientific documentation of the Harmonie-Arome deterministic forecasting and analysis system as provided earlier in Bengtsson et al. (2017) and Gustafsson et al. (2018).

E) Code efficiency and scalability

Efforts have been, and are being, made to improve the computational efficiency of 4D-Var through a better use of MPI and OpenMP parallelization.

A high-priority target is to achieve high-resolution (sub-km resolution) nowcasting ensembles, which are computationally highly demanding considering the tight time constraints for nowcasting. One important element for achieving this which has been experimented with extensively, is the continuous cycling approach mentioned earlier (fig.2). Another is the replacement of the linear grid by quadratic or cubic grids, which are computationally more efficient, at the loss of some effective resolution.

Various code adaptations have been made to permit use of single precision for Harmonie-Arome, on top of the work done by ECMWF (Vana et al.) and Meteo-France (Marguinaud) for the global models. Both the Reference 3D-Var and forecast model can be run (mostly) in single precision. Not all observation types have been added yet (radar, GNSS), or have been made to work in single precision (IASI still fails). For most variables, verification scores are indistinguishable between single and double precision, with the exception of a positive bias in mean sea level pressure increasing with forecast length and a slight tropospheric cooling in single precision runs. The cause for this bias and cooling behaviour is under investigation, but is suspected to be related to the radiation scheme. Using single precision, typical run time reductions of 35-40% are found. Next steps will be to get single precision to work with the full set of observations, establish the cause of the observed cooling and pmsl bias and alleviate this, and to test 4D-Var with single precision.

Figures:

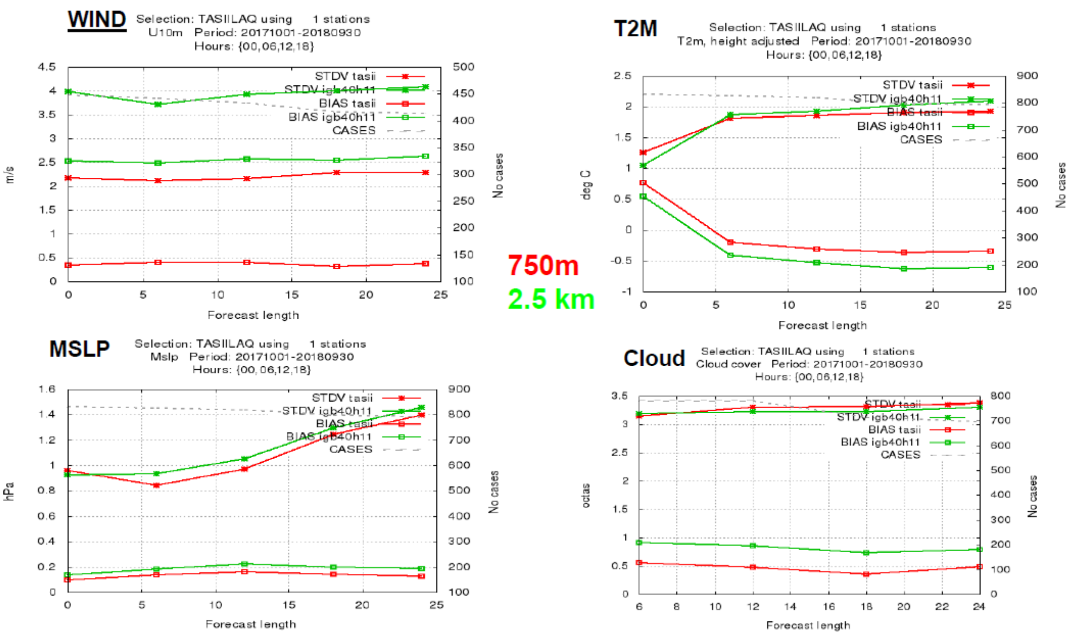

Figure 1: One year of verification of the 750m resolution Greenland Tassilaq domain vs the 2.5km resolution Iceland-Greenland (IGB) model. Standard deviation and bias are shown for u10, T2m, mslp and cloud cover; the red curves are for the 750m Tassilaq model, the green ones for the 2.5km resolution IGB model.

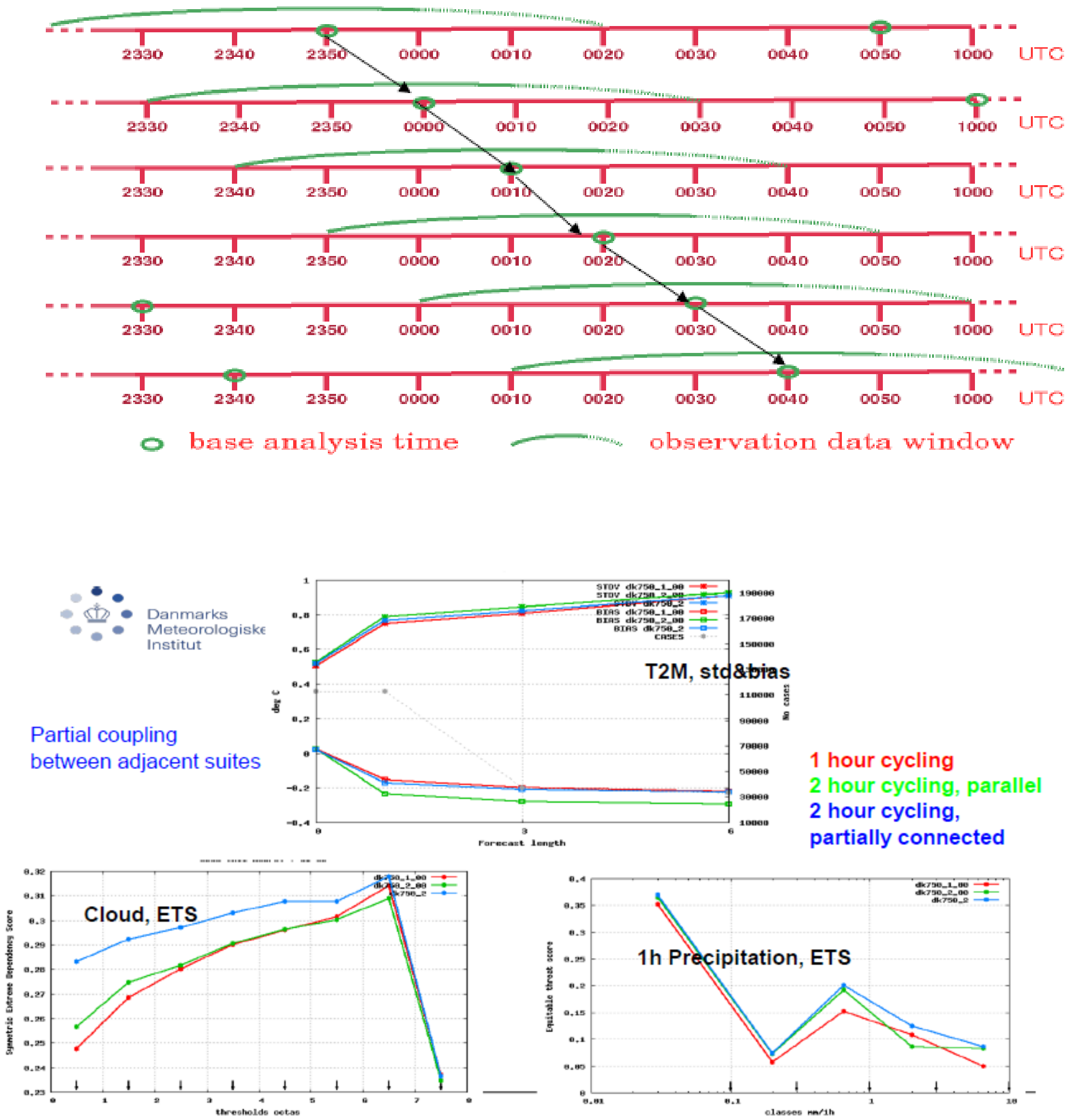

Figure 2: Top figure: setup of the partially connected 750m resolution continuous nowcasting ensemble suite for Denmark. The 6 sub-ensembles are partially connected through the adoption of the surface first guess from the most recent previous sub-ensemble. Bottom figure: impact of different choices for the cycling and assimilation time window options on T2m standard deviation and bias, and equivalent threat scores for clouds and 1h accumulated precipitation. The partial connection between sub-ensembles has a positive impact on the runs with longer time windows.