Report on HIRLAM Joint working week on DA and EPS 2013
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The goal behind HIRLAM Working Week 2013 is to initiate closer collaboration between two communities – the DA and EPS people. Furthermore understanding of challenges, problems in these two directions of research and designing a consistent EPS-DA system for convection permitting scales are also wished. This report is going to focus more on DA related questions and on the common DA&EPS issues and not going to describe the details of EPS designs, plans itself (mainly because the discussions were taken place in parallel sessions).

The following presentations were presented to initiate the Working Week:

Kai Settler (DMI) – GLAMEPS operational status
Maurice Schmeits (KNMI) – Improving GLAMEPS Wind Speed Forecasts by Post-processing
Sibbo van der Veen (KNMI) – Stochastic Microphysics in HARMONIE
Jan Barkmeijer (KNMI) – 4DVAR AROME
Jan Barkmeijer (KNMI) – Gaussian Quadrature 4DVAR
Nils Gustafsson (SMHI) – 4D-En-Var versus 4DVAR Hybrid in HIRLAM forecasting system
Ake Johansson (SMHI) – Another look on Spread and Skill
Tomas Landelius (SMHI) – Strategy for Surface data assimilation – towards the coupled DA system
Jelena Bojarova (Metno) – Constraining Large Scale Errors in HARMONIE
Jelena Bojarova (Metno) – Low norm regularization, coherent small scale structures and fronts

The presentations and programs can be seen on HIRLAM web portal: *https://hirlam.org/trac/wiki/DA-EPSworkingweek2013*

Presentations:

Presentation by Jan Barkmeijer discussed the future challenges of a HARMONIE, **AROME mesoscale 4DVAR**. The work on HARMONIE 4DVAR was already started in the HIRLAM community in 2008 and nowadays Jan Barkmeijer and Magnus Lindskog are working on it. However several arguments were raised against AROME 4DVAR development, HIRLAM DA people (mainly KNMI) still decided to set up this inside HARMONIE. Following challenges have to be considered during the development of mesoscale 4DVAR system:

- large computational cost of 4DVAR (especially on km-scale) with poor scalability
- many centers started development on different other approaches like 4D-En-VAR
- simplified physics is not available for AROME (AROME 4DVAR developments have to use initially ALADIN 4DVAR basics i.e. hydrostatic dynamics and simplified model physics of IFS or ARPEGE)
- Othe additional problems are expected to emerge hence the AROME model is using SURFEX and hence the humidity variable has a grid-point representation in the model.

On the other hand 4DVAR is a successful algorithm, US and MetOffice have already successful examples of km-scale 4DVAR and for next generation methods a reference (4DVAR) is also essential. The preliminary version of AROME 4DVAR has been already introduced to cy37h11 and first assimilation example was calculated which worked technically, but produced noisy increments. The

KMNI is allocating 1.5 FTE (full-time equivalent) during the next 3 years to progress in this area and to achieve a working AROME 4DVAR system in 2014.

Another talk by Jan Barkmeijer was taken about a new incremental 4DVAR algorithm which does not require computationally expensive integrations with the nonlinear model in the outer loops. The applied method is a so called **Gaussian Quadrature** which provides a solution to get an exact correspondence between the nonlinear time evolution of perturbations and the time evolution of the perturbation using the TL model. It was mentioned that linear models like TL in 4DVAR computation (also used in singular vector and in adjoint based diagnostics computations) have limitation that they are usable only for short-ranges. Through a simple example of linear equation it was shown that nonlinear growth of perturbations can be simulated by a linear model as well. To get the nonlinear growth a good combination of background trajectory and incremental trajectory should be selected with e.g. TL integration in order to capture time evolution of perturbations. Therefore linear models have still room on smaller scales, but we have to treat them a bit differently. This method in practice can be reached by an iterative procedure where we consider the complete incremental trajectory from the previous estimation as an independent variable. This iteration (TL iteration) can help also to merge in 4DVAR inner and outer loops which apparently reduces the computational costs. For more information the article of Stappers 2012 should be read.

The next talk was (by Nils Gustafsson) about the headline research in HIRLAM which is the development of the method so called **4D-En-VAR**. The motivation behind it is to replace 4DVAR which algorithm has some major weaknesses going towards finer scales. The 4DVAR minimization algorithm requires repeated sequential runs of a linear model (TL) and its adjoint (AD) which will be difficult to keep efficiently on computers with more (but not faster) processors. The method 4D-En-VAR is targeted to avoid using TL, AD and reduce the computational cost of the minimization. The potential of this scheme for the full-resolution NWP model has been demonstrated in the presentation but recently only in the framework of HIRLAM model.
More detailed description about formalism and differences between 4DVAR and 4D-En-VAR can be seen in Nils's presentation on HIRLAM webpage.
Briefly the proposed 4D-En-VAR scheme is going to combine the necessary components from Ensemble Kalman Filter (EnKF) and 4DVAR. In this scheme the static error covariance matrix so called B will be replaced by flow-dependent error covariances estimated from an ensemble of short-range forecasts and this is going to be employed for preconditioning as well. With this an ensemble of non-linear model integrations over data assimilation window will replace the TL model and adopt the idea of EnKF formalism (by the transformation of the background error to observation space), which leads to the fact that the AD model is elegantly avoided. In the derivative of this new cost function, the background error in observation space is calculated just once using ensemble forecasts outside the minimization iteration, so that the computational and coding costs are greatly reduced.
The next practical issue and one of the most challenging component of the 4D-En-VAR algorithm is the localization. This is necessary hence the affordable size of ensemble is far from the dimension of any operational NWP variational assimilation problem. To localize ensemble covariances the so called alpha control variable method (Lorenc et al 2003) is planned to implement which enable to precondition with a full rank localized matrix. The question of localization of covariances and good set of ensemble are the keys to good results, therefore collaborations and scientific studies on this area are wished in HIRLAM (and this is a burning topic in other centers as well).
Furthermore in the HIRLAM 4D-En-VAR the hybrid approach is going to be applied in order to combine a 3D-VAR First Guess Appropriate Time (FGAT) static B part with the ensemble based covariance part where the increments at different time slots are going to be formed as a linear

combination of a 3D-VAR FGAT increment and a 4D-En-VAR increment. With this combination (an outside computation of ensemble covariances and FGAT) the computational cost will be comparable with 3DVAR and application of linear model and its adjoint will be avoided too.

The next presentation (by Jelena Bojarova) was the introduction and discussion of the latest HIRLAM forum topic about “Constraining Large Scale Error in HARMONIE”. This issue was raised by Gert-Jan Marseille when he was testing HARMONIE DA with 3h RUC and comparing to dynamical adaptation of IFS with **large scale mixing** so called LSMIXBC. In HARMONIE the LSMIXBC was made by Ole Vignes which method is combining information from coupling and coupled model. On shorter wavelenghts and close to the surface the information from the background forecast is set to be dominant and on larger scales and approaching to the top of the model the driving model has bigger and bigger weight. The effect of LSMIXBC and DA using at the same time is not clear yet. Another study made by Per Dahlgren in HIRLAM model framework (Dahlgren et al. 2012) was mentioned which also combine large scales from the host model into the analysis of a regional model, but applying through an additional Jk constraint in the variational DA scheme. These two methods were discussed and agreed that use of large scale information improves forecasts. On the other hand comparison of two existing methods and more scientific studies are needed to get clearer picture and understand large scale mixing and DA connections.

The only **surface assimilation** talk was shown by Tomas Landelius who tried to gathering surface assimilation strategies for future strategies. Recently in HARMONIE there is an option to assimilate surface observations through CANARI+OI_main method which only consider the NATURE parts, tiles of SURFEX model and there are open, unowned assimilation challenges for the WATER, SEA and TOWN quantities. Within EURO4M project an 2D-Ens-VAR is developed where the analysis is projected into surface with OI_main to produce SURFEX initial conditions for HARMONIE forecasts. Hence OI and OI_main have limitation to include new observation types, EKF and EnKF are already developed in HIRLAM community for surface assimilation purposes. There were common agreement on that the EKF approach will replace OI in the future, therefore HIRLAM people want to cooperate in those projects which fit for this (KF based) method. A project so called SNSB (Swedish National Space Board) for Combined Meteorological-Hydrological Forecasting System will be a good framework for these purposes. As longer term possibility the 4D-En-VAR can be imagined to solve surface and upper air analysis simultaneously, but this option wasn't discussed further.

The last DA presentation (by Jelena Bojarova) was about **Low norm regularization, coherent small scale structures, fronts** as areas for future research topics. This talk discussed basically the results of three articles and a case study from HIRLAM forum (made by Gert-Jan Marseille with HARMONIE QuikSCAT wind assimilation). The first article (Duc et. al. 2013) and the case study tried to investigate the unobserved scales of the analysis and that how to judge those scales. Also it was highlighted that analysed small scale structures are not verified against low resolution observations and another interesting question was posed whether we should really correct these small scales by DA or not. The next article is addressing the problems of downscaling low resolution information into high resolution with other words adding high resolution details into low resolution image or fields. Regularization is the way to introduce additional information in order to solve ill-posed problem in a mathematical system. In the above mentioned article the low resolution precipitation field was projected into a spatially high-resolution field through an inverse problem which apply L_1-norm regularization. More details can be found in Ebtehaj et. al. 2012. The third article was based on the same regularization method but in variational data assimilation framework instead of precipitation image compressing. In this article the regularization can provide a more proper solution for usually noisy 4DVAR analysis which noises originate from the flow-dependency of the method i.e. the off-diagonal elements of the

background error covariances. Compared to the generally applied digital filter initialization the employed regularization provides less smoothness and better representation of sharp fronts. This procedure is described in the paper of Freitag et. al. 2013. In conclusion these issues were briefly touched as possible future directions and challenges for HIRLAM research, but the practical execution of these methods remains still an open issue.

Discussion

The first part of the discussion was about the large scale information mixing to the high-resolution model. The following statements, points were agreed on LSMIXBC and DA connections:

- The LSMIXBC method is overwriting the background forecast which holds DA contributions from previous analyses.
- LSMIXBC is efficient in HARMONIE, hence IFS provides good quality overall.
- Due to the different comparisons (LSMIXBC vs NoLSMIXBC) it was found the method and its results have large dependency on the applied representation of background error statistics as well.
- Using Hybrid method to consider large scale information would be more clear.
- Also the effect of LSMIXBC can be sensitive regarding the size of the domain.

In conclusion the optimal method for applying large scale information into high resolution model will be further investigated. Ole Vignes from Norway is going to work more on LSMIXBC and Swedish team work more on Hybrid method Jk term for large scale mixing.

Another issue was discussed which type of structure functions, representation of B should be optimal for small scale and high frequency observations like RADAR data. An NCAR study for Olympic games 2008 was mentioned by Nils which study tuned the length scales of the structure functions in order to improve contribution of RADAR observations. On the other hand when one reduces length scales one should adopt balances i.e. the balance operator has strong scale dependency as it was said by Nils as well. For the time being available a posteriori tuning methods like Desroziers should be beneficial and easy to use in case of introducing new observations.

For next the flow-dependent background error statistics are wished to achieve in order to use observations more accurately in the high-resolution model. To achieve this 4DVAR and 4D-En-VAR activities are already started where 4DVAR is going to be a reference and 4D-En-VAR is the ultimate goal to develop in HARMONIE. It was again mentioned that 3D-VAR FGAT is needed to get 4D-En-VAR with HIRLAM approach and some future work also needed to overview 3D-VAR FGAT from 4D-En-VAR point of view. This is because the 4D-En-VAR has an important similarity with 3D-VAR FGAT, namely that the background constraint is defined in the middle of assimilation window. On the other hand 4D-En-VAR has an important similarity with 4DVAR as well, namely that the time variation of the increment is treated like 4DVAR.

The general constraint is to keep coding norm of OOPS project which should be considered during every future developments. On the other hand the relatively slow progress of OOPS releases HIRLAM community won't wait anymore for OOPS regarding their development, but try to keep the OOPS compliant way to avoid future code porting inconveniences. It was also mentioned that 4D-En-VAR without OOPS layer and OOPS compliant way would be so much work for HIRLAM so collaboration with Meteo-France people are highly desirable to share this development.

Regarding surface assimilation issues the EKF method is going to be relevant in the future and HIRLAM community is going towards this. Also for snow analysis requirements EKF is wished to apply.

Video-Conference Session with Meteo-France (MF)

The discussion with MF colleagues (Claude Fischer, Gerard Desroziers, Loik Berre and Francois Bouttier) was started with Gerard's presentation (from WMO DA symposium 2013) which studied the 4D-En-VAR and its link with 4D state formulation and different possible implementations. With formulation of 4DVAR and 4D-En-VAR it was shown that the cost function of both method has the same shape, but in the Jb term B matrix is different, because in 4D-En-VAR it is based on 4D perturbations given by an ensemble evolving in time (similar to Nils's presentation). Concerning the possible implementations there were 4 options mentioned where the first is based on the results of Canadian Meteorological Centre especially Mark Buehner and an approach which includes spatially localized ensemble representation of the correlations. The second possibility is to apply alpha control variable for 4D-En-VAR implementation which proposed by Andrew Lorenc from Met-Office. In the OOPS toy model framework there are 2 other ways which are already existing. One is a kind of algorithm which can help to avoid using the change of variables procedure, so the control variable remains in the origin space (dx formulation). This method was tested for 4DVAR and can be applied for 4D-En-VAR as well. Second OOPS implemented option is similar to the previous one but applying additional step to reduce dimension of the control variable and project into observation space (dy formulation).
With a 4D-En-VAR (Burger's toy model) experiment where only three observations were assimilated it was highlighted that at the initial time of the assimilation window(t+0h) the 4DVAR and 4D-En-VAR provide very similar increments, but at the end of the window(t+48h) the 4D-En-VAR wasn't able to capture increments properly, hence fast moving wind field and inefficient spatial localization. With shorter assimilation window(t+6h) the problem was mainly solved and the convergence of the two algorithm were almost the same. (Ensemble size L=100, Localization length Lc=1500)
The Hybrid formulation was also briefly presented which allows to consider static and flow-dependent representation of background error statistics and provides more realistic increments.
In conclusion the implementation of “dx formulation” or “dy formulation” for 4D-En-VAR are foreseen by MF colleagues, but further works especially with collaborations on efficient localization in space and time are expected.

After the above discussion the HIRLAM colleagues were presenting their findings from the previous working days (see above) a short discussion was opened to define common work to share with each other. As a result, the localization in the 4D-En-VAR algorithm was identified as the main and first point for future collaboration between MF and HIRLAM.

Summary

To conclude the HIRLAM WW from the DA (and my personal LACE DA AL) point of view the following important statements can be summarized:

- The HIRLAM community has already major **scientific knowledge** on headline algorithm developments like 4DVAR, 4D-En-VAR based on HIRLAM model framework.
- Furthermore HIRLAM has lack of knowledge on the relatively new HARMONIE and mesoscale modeling areas which is obviously desirable for the development of future

operational forecasting **systems**.

- (In an ideal center, both the "scientific knowledge" and its application in the "operational system" would be kept in a similarly high level)
- **DA and EPS** people can/should share their knowledge and work together in order to benefit from cross-cutting issues like flow-dependent DA and Ensemble DA for the perturbation of initial conditions in probabilistic forecasting.
- In 4D-En-VAR a **good set of ensemble** might be more important than just bigger size of ensemble.
- **Localization** becomes a key element of next generation DA algorithms which should be revised in scientific context (instead of its ad hoc application) and should be applied to extract information from limited size of ensemble.
- The **OOPS project** and layer are very important on the long term, especially for DA developments. HIRLAM DA community will start to progress with their development side by side with OOPS and keep the OOPS compliant way.
- (The OOPS framework is extremely important in order to stay at an up-to-date level of DA developments and researches.)
- HIRLAM has enough manpower to refine and extend the existing development. Also AROME 4DVAR is going to be developed in HIRLAM community and the necessary investment is also going to be made to use 4D-En-VAR in HARMONIE (revision of 3D-VAR FGAT, Hybrid etc).
- The surface assimilation issues are yet coordinated in a lesser extent within HIRLAM. EKF will get more emphasis in the following years.

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