Norwegian Meteorological Institute

SMHI

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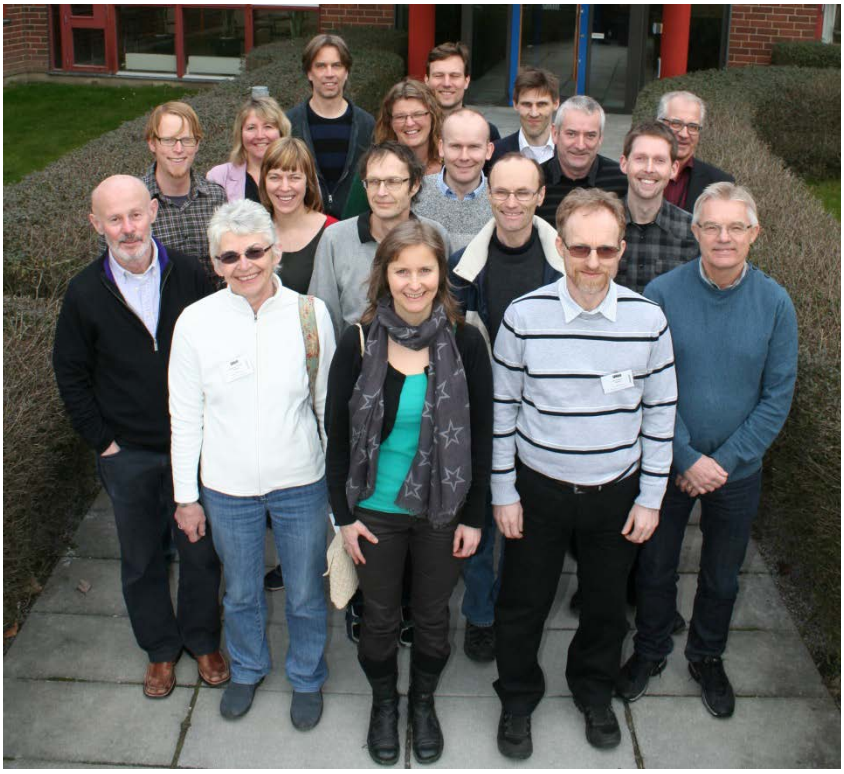
MetCoOp – Meteorological co-operation on numerical weather prediction (NWP)

Final project report

Solfrid Agersten, Bodil Aarhus Andræ, Jørn Kristiansen, Heiner Körnich, Camilla Husum Vold



Front picture: Participants from the steering group and project group.
Front left: Lars Meuller[S], Rebecca Rudsar[M], Solfrid Agersten[M], Ole Vignes[M].

2. row left: Per Dahlgren[S], Camilla Husum Vold[M], Karl-Ivar Ivarsson[S], Knut Steinar Dale[M], Bo Strandberg[S].

3.row left: Anita Gelfgren[S], Bodil Aarhus Andræ[S], Morten Køltzow[M], Dag Bjørge[M], Arne Sund[M]
Back row left: Martin Ridal[S], Heiner Körnich[S], Jørn Kristiansen[M], Håkan Borg[S]

[M] for MET Norway and [S] for SMHI

MetCoOp

Meteorological Co-operation on Operational NWP (Numerical Weather Prediction)

Norwegian Meteorological Institute
and
Swedish Meteorological and Hydrological Institute

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METCOOP MEMO (Technical Memorandum) No 01, 2015

MetCoOp – Meteorological co-operation on numerical weather prediction (NWP)

Final project report

Solfrid Agersten

Summary

This report is a project evaluation report for the MetCoOp project which ran from August 2011 to March 2014. The main objective of the project was to facilitate the common production of numerical weather prediction forecasts between SMHI and MET Norway. The Numerical Weather Prediction (NWP) model used is HARMONIE AROME with a horizontal resolution of 2.5 km. The spatial domain covered both countries plus some adjacent areas. Researchers worked (also together with people in the HIRLAM consortium) to improve the model forecasts and to assimilate more observation types, such as radar data for example. When the NWP model runs it needs a High Performance Computer (HPC) to achieve suitable performances for operations. A lot of effort has been done both to set up the model system and to set up a proper scheduler system to control the different tasks in the common production. The first HPC used is "Vilje", which is located in Norway, with a backup at the HPC in Sweden. The two institutes take turns operating the primary HPC.

The project group contained different competence and worked well together with a clear goal. This setup was experienced as a good point by the participants. 4-5 persons from each institute were dedicated to work on the project for at least two days a week. They met on a common video meeting twice a week sitting together in the project-rooms. Approximately, they met physically every 4-6th week, either in Norway or Sweden to discuss, review and arrange future plans. People interested in the project progresses followed open and streamed meetings (reviews). Many different solutions were evaluated before taking every decision. In fact, the process of setting up a new system (and especially an operational system) involving both institutions must take into account the respective IT-competence, servers, network, monitoring-systems, different operational routines etc. Good communication between the organizations and between the researchers, model developers, IT-people and meteorologists/forecasters was needed to avoid delay in the project schedule. This communication is still required every day when the production of numerical weather predictions is operational. See also chapter 4 "The experience of the organizations and the participants» and chapter 5 "Experiences and recommendations".

In the first chapter of this report, facts about the project are described. Thereafter the different goal in the project are reported. The work on 18 different requirements as different aspects of the project are described in detail, and the results of these are described in chapter 2.5 " of requirements, delivery items" followed by some words about cost, time and milestones. In chapter 3 the project methodology and progress are described. The Scrum-methodology was adapted to the framework to co-operate between countries and organizations and also between different disciplines. The project was not an IT-project (with small deliveries of working program-code) and not a research project, but gained a lot by working agile and using the main ingredients of Scrum e.g; daily standups, planning in short-term (4-6 weeks ahead), delivering after every sprint. It was found to be a good practice to travel every other sprint to the other country and to stay there for a couple of days to work together.

Feedback from the organizations is outlined in this report and shows that MetCoOp has been an open project with possibility to read about or listen to the monthly sprint reviews as status. Both the IT- and research areas at the institutes have gained in this collaboration project. The resulting model-system and common operations are very welcome. Valuable thoughts exist about future co-operation both in the field of HPC, research, forecasting and user-focus on how to apply the results.

Experiences from the internal evaluation of the project group are also shared in this report. To summarize the following aspects were regarded important:

- Plan early enough and work with anchoring of the project in the organizations
- Finding what competence is necessary and involve people with this competence
- Work together in team across disciplines (and countries)
- Give people responsibility and point out clear goals
- Regular meetings on video and physical meetings and workshops are necessary
- Continuous deliveries and focus on the right tasks gave progress
- Do not underestimate decision processes that involves users and/or decision makers at the involved institutes
- Necessary to have an early focus on IT-technical solutions and prepare for the implementation phase; it will probably be more complex and some unforeseen issues might happen.
- Organizational issues take a lot of effort and time.

The persons in the project group were from SMHI: Lars Meuller, Lars Berggren, Per Dahlgren, Martin Ridal, Karl-Ivar Ivarsson, Anita Gelfgren and from MET Norway: Dag Bjørge, Morten Køltzow, Ole Vignes, Arne Sund, Rebecca Rudsar, Knut Steinar Dale, Solfrid Agersten.

The steering group consisted of: Bodil Aarhus Andræ and Heiner Körnich (earlier was also Håkan Sanner involved) from SMHI and from MET Norway Camilla Husum Vold (earlier Roar Skålin) and Jørn Kristiansen.

Thanks to all people that made this project possible, from all disciplines at the institute, users, collaborators and the HIRLAM community, all the way from the early initiative of the project to the end of the project and into the operational phase!

Special thanks to the steering group for help with this report and Dag Bjørge (MET) and Cristian Lusanna (MET) for editorial help.

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1 Facts about the project

The MetCoOp project focused on the development of numerical weather prediction (NWP) system and on the buildup of a common setup of the NWP operations for Norway and Sweden. The present “final report” of this project describes progress, goal achievements, results, experiences and recommendations for future activities.

1.1 The project

1.1.1 Project name and identification

MetCoOp - Meteorological Co-operation on Operational NWP (Numerical Weather Prediction). This abbreviation stands for meteorology, co-operation and operations, which are the three pillars of the project.

1.1.2 Principal and contractors

Figure 1. Signing the contract in 2014: From left the director of Meteorological services in MET Norway Jens Sunde, director-general of SMHI Lena Häll Eriksson, director-general of MET Norway, Anton Eliassen and director of Meteorological services at SMHI Bodil Aarhus Andræ.

The directors of the Swedish Meteorological and Hydrological Institute (SMHI) and of the Norwegian Meteorological institute (MET Norway, earlier met.no) decided to establish a co-operation on NWP activities. As a first step a preliminary evaluation study was conducted in 2010 [1], then a steering group were settled later the same year. In 2011 a project leader was appointed and both a project directive [4] and project plan [3] were prepared during the spring. In August 2011 a project group started its work and in September 2011 the official agreement [2] between the parties was signed by the directors. In March 2014, the project ended and the running of NWP model in co-operation entered its operational phase.

Orderer / Project owner:		Project manager:
______________________	______________________	______________________
Bodil Aarhus Andræ (steering-group leader) SMHI	Camilla Husum Vold (steering-group) MET Norway	Solfrid Agersten

1.2 Background

Project objective from the Project plan [3]:

The global models (as from ECMWF) have an increasing quality, so it is of great importance that SMHI and MET Norway deliver better weather forecast than this for the local domain that SMHI and MET Norway is responsible to deliver short-term weather forecast for.

It is a very time consuming task for both SMHI and MET Norway to test and verify new model versions. SMHI and MET Norway run the operational model for more or less the same domain, and have co-operated in different areas already so it will be beneficial to co-operate on sharing High Performance Computer (HPC) resources and run the same operational NWP model.

A common approach is also recognized to be of strategic value, in order to secure the participating institutes a role in the future NWP-production community.

It is also a risk that the institutes relay too much to too few people with the right competence. It should be a described common responsibility for always keep the right and enough competence to this important part of the met institutes to run the operational numerical weather prediction model.

1.3 Summary

1.3.1 Project scope

Project idea and goal from the Project plan [3]:

SMHI and MET Norway should produce the best short range numerical weather forecast for the common domain.

A common approach will give access to and more optimal use of available human and computing resources.

It is proposed that this project also should facilitate closer cooperation in other areas of the meteorological institutes.

When operating together it is expected to have advantage of each other's experiences and R&D resources.

1.3.2 Interdependencies to other organizations

Most of the development of the HARMONIE model system is done in the HIRLAM-ALADIN partnership. In the HIRLAM community it is close contact and collaboration between the scientists in different countries being experts on different topic regarding the NWP model system. SMHI and MET Norway have for many years been partners in this collaboration. MetCoOp experienced large gains to be part of this and to work close together with the NWP scientists at SMHI and MET Norway. On the other side MetCoOp experienced positive feedback as a cooperative partner since the work-packages were organized in a project with milestones and goals. In the Hirlam A evaluation [7] it is proposed for countries to cooperate also on operational NWP production and in this perspective SMHI and MET Norway can possibly be an example for other countries in the European NWP collaboration.

Developments on the HARMONIE AROME model system in different internal and external research projects, e. g. with focus on assimilation or on the user experience of a "good forecast", have yielded results for the MetCoOp project also.

MetCoOp (together with DMI) had a RCR (Regular Cycle of Reference) responsibility for HARMONIE Cycle 38 from spring 2013. This responsibility resulted in a focus on testing the new version of HARMONIE to verify different aspects of the forecast result. The focus on the next version disturbed in a way the focus on tuning the model system for the MetCoOp area and it was experienced some differences between the versions that were not so good for the area of interest. Norway had an older version of HARMONIE running that for some periods and some parameters had better verification scores, so a difficult decision for MetCoOp was to be loyal to the RCR responsibility to set focus on the improvement potential for the next version. The RCR responsibility gave a close and good co-operation to the HIRLAM management group especially on the model system and application and turned out to give valuable mutual results between MetCoOp and the HIRLAM community.

There were some concerns about who should take care of the downstream users of SMH and MET Norway. Since the project had a long time frame, the project informed the organizations, and the organizations took care of the consequences for the downstream users. At Met Norway it was decided to run the high-resolution model HARMONIE AROME also before the MetCoOp model system was operational. This decision resulted in an unequal experience in the countries of the effect of the introduction of MetCoOp (Meteorological Co-operation on Operational NWP). Nevertheless, the common focus at SMHI and MET Norway to both develop and run operationally the same model-system was a major factor for the success of the MetCoOp project.

2 Goal achievement

2.1 <u>GOAL:</u> "SMHI and met.no should produce the best short range numerical weather forecast for the common domain."

Achievement comment: This goal was achieved for all of the parameters except for temperature in the winter, as shown in the verification. Summary from report [5] Køltzow et.al, 2012 showed that AROME gives the overall best result on wind and small precipitation amounts of the compared models. The comparison included the global model from ECMWF (16 km resolution), UM (Unified Model from MetOffice on 4 km resolution run by MET Norway) and HIRLAM (5.5 km resolution). AROME was in general not as good as ECMWF on MSLP and total cloud cover. The result for temperature was dependent on region and type of verification score, and HIRLAM gave in general better scores than AROME, but AROME was better than the other models. The report showed that it is work to be done on AROME to improve the model on total cloud cover.

This investigation and its conclusion was the final argument for the decision to co-operate on HARMONIE AROME between the two institutes in their operational short-term forecast NWP system.

Before the MetCoOp model system was set into operation in 2014, a new verification study was done based on extensive experiments and tests on HARMONIE CY38h1 from early 2013 until the beginning of 2014. A summary of this can be found in Annex 1 in this report. The verification study was provided to the HIRLAM management group from MetCoOp as a RCR for cycle38. For MetCoOp it yielded the basis for the decision to upgrade from cycle37 to cycle38.

The differences between the HARMONIE AROME versions 38h1b3 and CY37h1.1 were small for wind. CY38 was marginally better for precipitation and total cloud cover and generally better for relative humidity. For 2-m temperature cycle 38 was somewhat better in summer, but somewhat worse in winter due to a pronounced negative bias. This issue was reported as a suggested area of development [9].

Compared to ECMWF HARMONIE AROME CY38h1b3 showed better results for precipitation and wind, generally the same quality for relative humidity and for temperature clearly better result in summer, but somewhat worse in winter. ECMWF had better forecast of total cloud cover than HARMONIE AROME.

MetCoOp had regular operation of NWP from March 12, 2014 which included both the HARMONIE AROME 2.5 km model and a 11km-version of HIRLAM (a continued version of SMHI's local HIRLAM version). The meteorologists from both institutes had been using the test-version of the MetCoOp NWP model for a long period already by then. SMHI started parallel production to downstream products more or less the same day and by March 31, the production was based on the MetCoOp NWP production. SMHI turned off 3 different operational HIRLAM versions in April 2014, except for HIRLAM 5.5 km because of the low runtime cost and the high quality of the temperature forecasts. At MET Norway a local version of HARMONIE AROME cy.37 had been running for almost a year, and the new version from MetCoOp did not show better result on all parameters (as explained above). With the promise of development of the model-system on the issue for winter temperature and work on an optimal post-processing, MetCoOp NWP-forecasts was released for *yr.no* and other downstream use in the mid of May 2014 and the local version of AROME turned off in June. Met Norway still runs their local versions of HIRLAM with 12 km and 8 km resolution but with no development and diminished use.

2.2 <u>GOAL:</u> "A common approach will give access to and more optimal use of available human and computing resources."

Achievement comment: This is true, but it is not possible to fully realize the goal before the old national large scale HIRLAM models will be turned off and new HPC resource will be available at SMHI. It is worth remarking that computing resources will be strongly needed when a common Ensemble Prediction System (EPS) will be in operational use for both parties.

To run the project as an agile project with people sitting and working close together with milestones and frequently delivering of results was successful. When people in the project-group met often, problems were solved more rapidly when focus was on solving impediments. It was also experienced that a good collaboration between the parties in the field of research projects and IT-challenges contributes to solving problems related to goals in MetCoOp. The meeting-points between meteorologists and model-developers and the MetCoOp group give better understanding of the weather forecast and better services for the users.

The last six months IT-operational personal worked close together to establish the organization for the operational phase. This work resulted in a flexible solution, using already existing personnel at the institutes. The scheme for operational tasks in MetCoOp is a 24/7 monitoring "servicedesk" at MET-Norway and on-call service of experts from SMHI (IT and NWP-model), see also *Figure 17*. The organization after the project phase consists of a matrix of persons working on-cross of the organization with focus on the operational system and development of the model-system. This organization is optimal in the way that the focus is on close collaboration between the key-personnel and on safe operations with best possible NWP forecasts.

2.3 GOAL: "It is proposed that this project also should facilitate closer cooperation in other areas of the Meteorological institutes."

Achievement comment: SMHI and MET Norway have a long tradition of cooperation in many different areas and they still do cooperate, but MetCoOp is special in the sense that it is an operational co-operation.

Some more initiatives on co-operation on DIANA development (which is a forecaster's tool and an open source initiative from MET Norway) have been realized. Although not so many co-operations initiatives have been promoted on the forecaster's area, a number of forecasters from one country have joined the other country's learning program. The forecasting groups have been more informed about experiences and forecasting culture in the other country. There are also more initiatives to come, for example to inform and talk to each other in case of extreme weather, verification work and the possibility to sit by the others work place.

The latter part of the project required an intense cooperation in IT-operations (service-desk 24/7) and IT-infrastructure. Regarding the future operational co-operation, closer contact and more optimal and possibly more long-lasting, common IT-solutions related to routines, tasks and tools shall be pursued.

2.4 GOAL: "When operating together it is expected to have advantage of each other's experiences and R&D resources."

Achievement comment: Since the project started, meetings between the NWP researchers have been held, several development projects are in progress, and some more project will start. SMHI and MET Norway are both very active in the HIRLAM/ALADIN co-operation initiative to develop and improve the numerical weather prediction model system HARMONIE so a lot of the common research and common development work are organized there.

The project-group delivered a report with recommendations for further development which will be organized in smaller co-operation projects or activities between the two institutes. The leader of the development work in MetCoOp will coordinate the different activities and make sure that the results achieved during the development phase will be implemented in the operational model-suite.

2.5 Results of requirements, delivery items

The main deliverance of the project is a common production line of the non-hydrostatic high-resolution model HARMONIE AROME from observations handling to NWP model result.

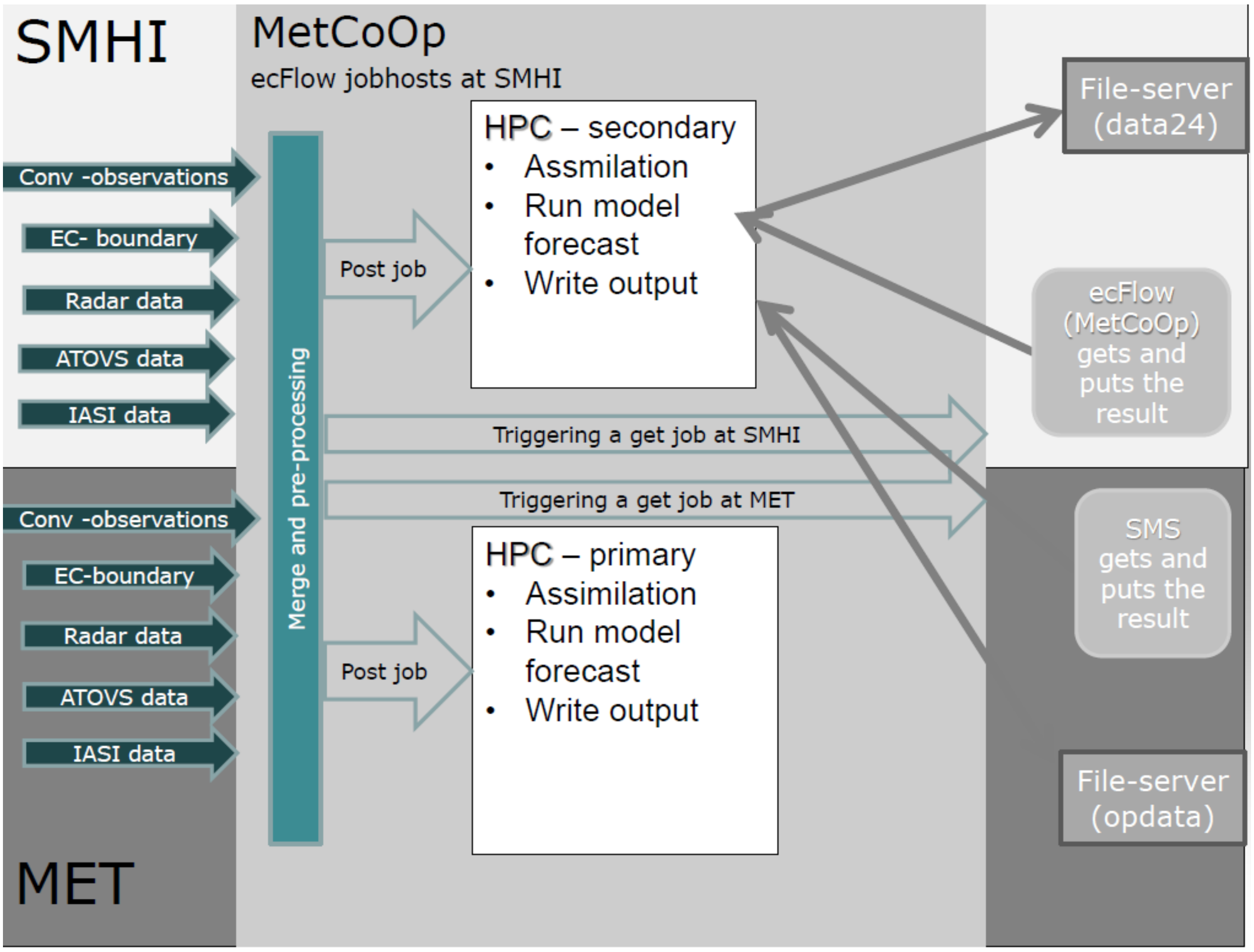

Figure 2 Overview of the MetCoOp system; dataflow of observations and input data from SMHI (light grey at the top) and MET Norway (dark grey at the bottom), MetCoOp system in the middle – the white boxes are the HPCs that are running the NWP model.

The table below shows the deliveries by the project as described in the project plan (first two columns). The evaluation comment of the delivery is given in the right column:

Delivery description	**Approval criteria**	**Final delivery comment**
Common scheduler & queuing system		The scheduler system ecFlow runs on common infrastructure and schedules the main and backup runs…
Common operational deterministic NWP model(s)	The model(s) is available to run on common HPC from SMHI and MET Norway and output are accessible	…for the deterministic NWP models HARMONIE AROME2.5 km and HIRLAM 11 km. The results are available…
Deliver model output for a certain common domain in a certain format.	The model output is technically usable and it gives as good or better result in the user “applications” than before.	…in GRIB format with parameters and fields specified by the user. Verification of HARMONIE AROME shows that the results in most occasions give the best forecast.
Common production of pre-processing of observations		Redundancy is chosen for the incoming observations and some pre-processing is done.
Common short term archiving of the formatted NWP-model output.		A common short term archive was evaluated, but found that it was not recommended for the time being. Each institute will store the common results and have their own archive preferences.
Common production of verification result		A verification system (WebGraph) is chosen, and daily verification are available for the organizations on a web site. Some smaller issues were left for this to be operational in March 2014.
Common system for Ensemble Prediction System (EPS) production		Because of the delay of Vilje (MET’s HPC) and the postponement of the procurement of the next HPC for SMHI, it was not possible to start with EPS production in the project phase. It is recommended to prioritize this task in the phase to come to set a HarmonEPS in operation in Q3 2015 on the new HPC.

The project has delivered a framework for an operational organization on common NWP production. This organization has been settled and it takes the responsibility for the administration of further operations.

All deliverables reported in the list of the ProjectPlan [3] are available, so that the Operational Group can take the responsibility of the MetCoOp operations. However, there will always be tasks to improve the operations and developments are always needed. Therefore, the project issued to the MetCoOp operational organization a summary with recommendations for areas where further development are needed.

The several tasks done in the project was grouped in 18 points in the project plan. The requirements served as input categories to the Scrum (see [8] and Figure 18) project to ensure that all tasks in the project should be done. In the sections below the requirements and the fulfillment of them are shortly described.

2.5.1 Observation handling

An optimal selection of the data available from SMHI and MET Norway in operational and research model runs should be used. The use of observations takes into account and respects possible restrictions on data policy; it is worth noticing that the availability for common production does not imply any redistribution of constituting observational data.

a) **Conventional observations** contain SYNOP, SHIP, DRIBU, AIRCRAFT (amdar, acar, airep etc), TEMP and PILOT.

At SMHI both local and global conventional observations go through MESSIR. MESSIR, which is commercial software from COROBOR, is the message switch used by SMHI.

The observations are thereafter sent to the quality control system (software KVALOBS and some functions in common with MET Norway). During the project period the MetCoOp server was located in Norway, and the observation data from SMHI used 'ahttps' for downloading waiting for the cut-off.

In MET Norway the NORCOM system is used for collecting observations and the operational SMS (scheduling and messaging system) was used to push the observations to the MetCoOp server at cut-off time. The data used for NWP is open and free data, and cause no problems in the transfer.

In a previous project, the possibility of a co-operation both in the observation collection process and in the further distribution of the pre-processed observations into the GTS (Global Telecommunication System) was investigated. The conclusion was that these processes are different for the two countries because of national decisions. Furthermore, observations are fundamental in most of the downstream processes for both meteorological institutes. As a result, it was agreed in MetCoOp that a closer co-operation in this area could be more relevant later when the systems should be upgraded.

The project also concluded that a common data quality control system as a pre-processing of the observations before entering the model system would have a strong positive impact. The KVALOBS system is developed by MET and it is open source. This system is also (partly) used by SMHI (but not on the same "time"step in the process).

Work has been done to include snow measurements, and there are more data-parameters to come, like for example Sea Surface Temperature (SST).

b) **Radar data** from Norway and from Sweden.

Radar data are also included in the dataflow of observations from the institutes. The data from the radars were not so easy accessible and a lot of effort was done to retrieve the data regularly from both countries in order to use them as input to the assimilation system.

In Figure 3 it is shown that radar data from Norway are provided by an open source system, called PRORAD that include a quality control. The data are stored in XML files, which are converted to MF-BUFR by CONRAD, a pre-processing package in HARMONIE. The radar data from SMHI are quality controlled using the free software BALTRAD and the data are in HDF5 format, which now can be used into HARMONIE.

Using radar data in the assimilation gives neutral or positive impact on the forecast, but work is still in progress. For more information see 04-2013 METCOOP MEMO: "The use of radardata in HARMONIE AROME for MetCoOp. Validation of first results" (Ridal et.al) [6]. Radar data will be included in the operational model-suite soon, starting with assimilation of reflectivity where data amounts will be reduced due to memory limitations in the HPC and to correlated observation errors. MetCoOp had planned to assimilate radar-data from the beginning of the operational phase, but regrettably there were both problems in how the assimilation system used the radar data, (e.g filtering mechanisms), and also some technical issues connected to the setup of the 3dVar assimilation of this new observation type. MetCoOp had not enough people to focus on this, and HIRLAM management seemed to wait for results from MetCoOp…. Other countries in the HIRLAM community experienced somewhat similar problems. If there had been some more common focus and workshops on this topic in the research groups at MET Norway, SMHI and in the HIRLAM countries, the problems could probably have been solved earlier.

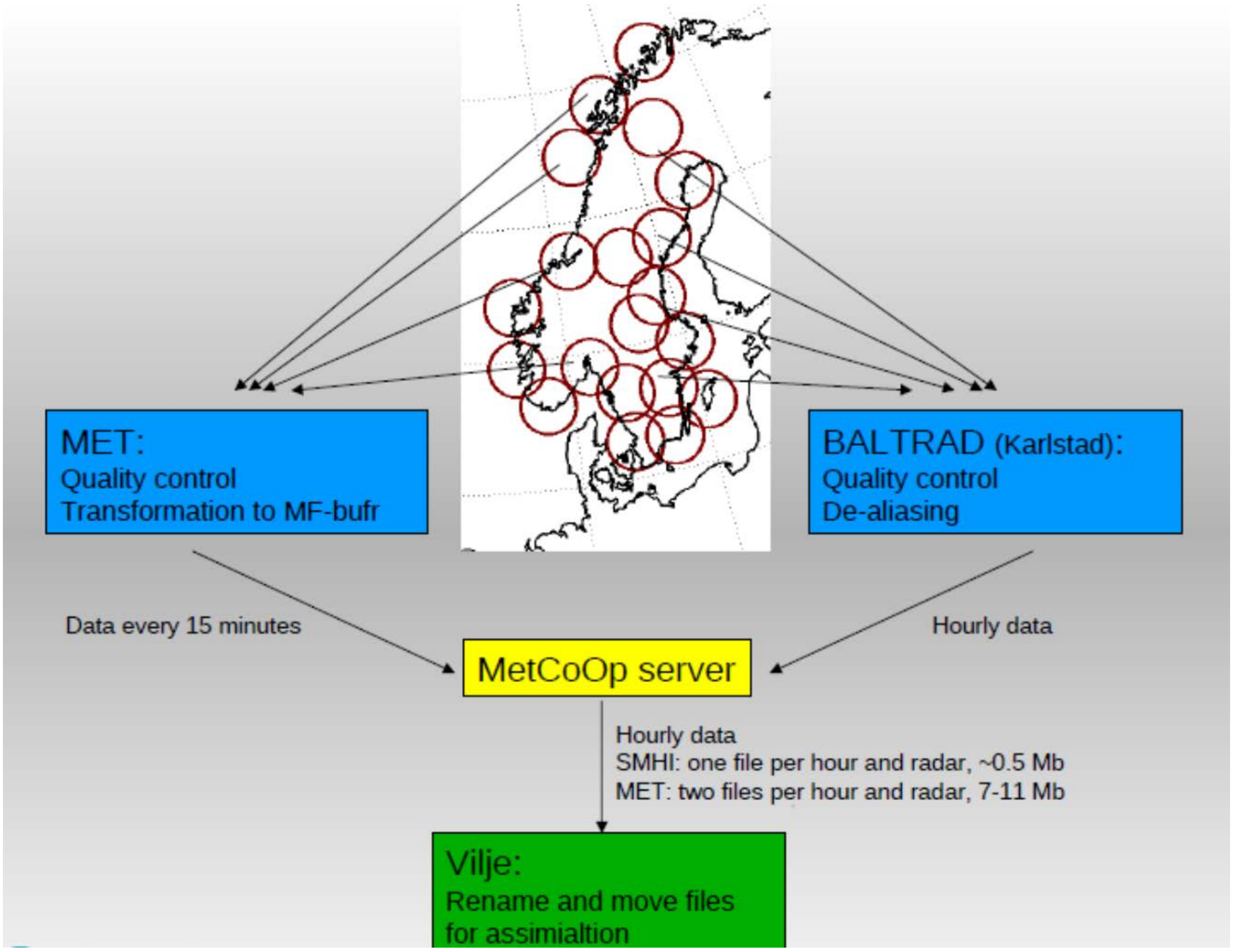

Figure 3 Overview of the dataflow of radardata in MetCoOp.

c) New observation types as ATOVS data have been proven useful in research and they are also introduced for operational use. EUMETCast is the EUMETSAT's distribution system for satellite data.

ATOVS data is sent via a communications satellite. ATOVS processes the following satellites and instruments:

NOAA15 amsu-a, amsu-b
NOAA16 amsu-a, amsu-b
NOAA18 amsu-a, mhs
NOAA19 amsu-a, mhs
METOP-2 amsu-a, mhs

Both MET Norway and SMHI get these data and the data sent to the MetCoOp server. A duplicate dataflow gives a more reliable chain; furthermore it reduces the risk of data loss during the NWP model run.

Technical and scientific work has been done in order to assimilate satellite data and IASI data in HARMONIE AROME.

d) Finding optimal cut-off time.

The cut-off time has been optimized according to the data availability in time with the goal of collecting the maximum number of observations. For radiosondes, which are of special interest, only few data from station located at the border did not arrive in time (see Figure 4).

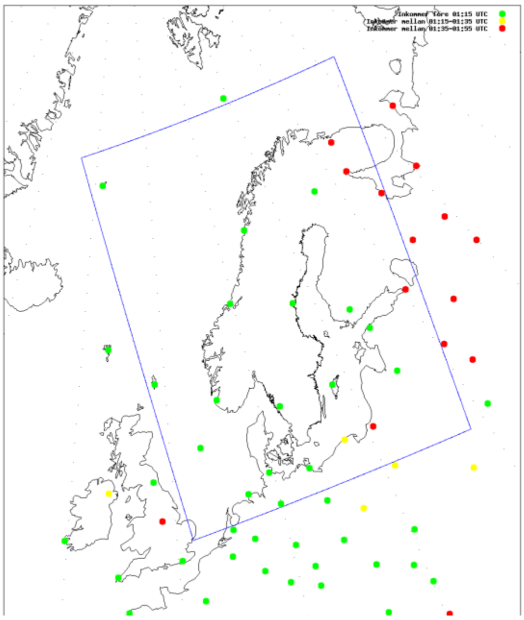

Figure 4 At 20130502 00, Green – before 01:15, Yellow – 01:15-01:35, Red – 01:35-01:55 UTC

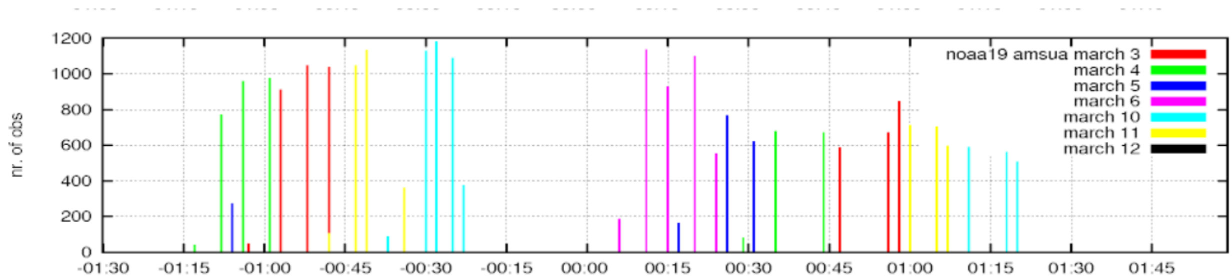

Figure 5 NOAA19 AMSU-A arrival times o SMHI for a 12UTC AROME run.

For surface observations (SYNOP) it was found that some observations were missing at 00 UTC with a 1:15 cut-off time (not shown). As the high-resolution model has a quite long runtime, it was decided to use 1:15 hours as the operational cut-off time in order to reduce the total time. It was expected that a quality-reduction of the result was negligible, but was not examined further.

The observations used in MetCoOp contain also ATOVS data. From Figure 5 it can be seen that no loss of satellite data after 01:15 at 12 UTC could be found, but during the night time a significant loss was found.

2.5.2 Pre-processing of observation data stream

The chosen interface for pre-processing of the observation data stream is run in common and the source code is shared. Common software between the Nordic countries for the preparation of observations to enter the NWP system already existed, however slightly different versions were used. The software code is now shared in a common version control system. The code contains methods for merging the observations of both countries and for removing duplicates is also stored in the common version control system.

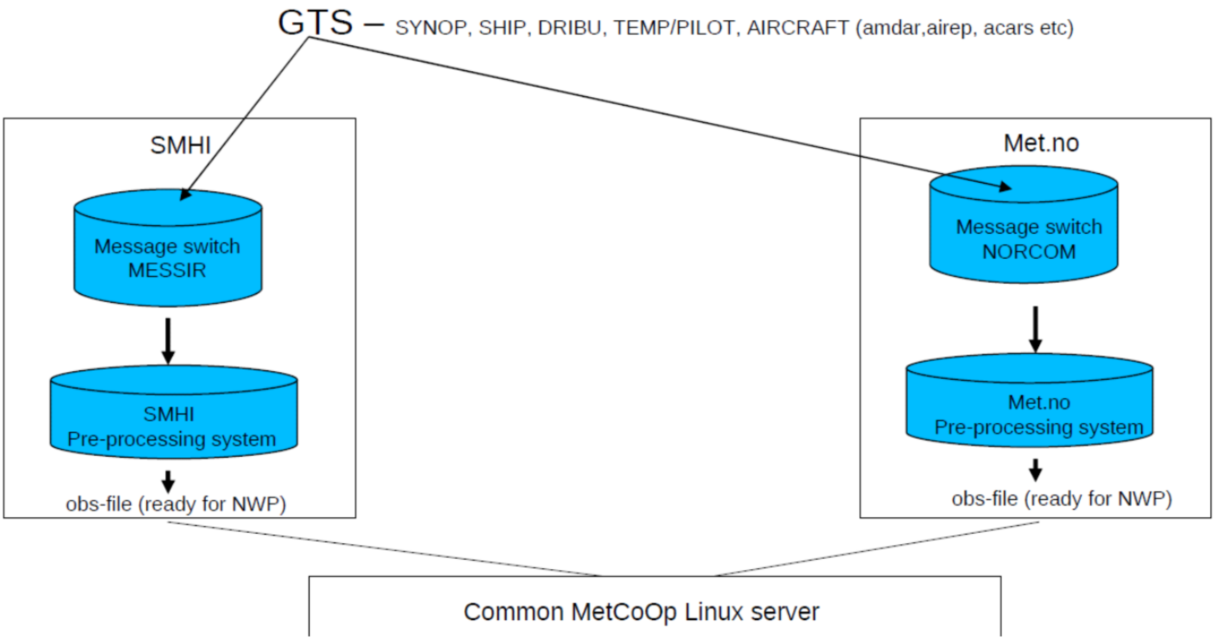

Figure 6 Observation collection and processing system in MetCoOp.

A decoding for the ATOVS data was set up for MetCoOp. Data outside the MetCoOp domain were removed from the satellite dataset and duplicate data do not enter the NWP assimilation. Experts compiled a valid “blacklist” of different instrument channels from the satellites to be used in the operational model-setup, so that the satellite data entering the assimilation process are used in a proper way.

HARMONIE does also have its own quality control system, which has been further developed for radar data (for reflectivity and wind components). The HARMONIE system had to interpret the quality flag information provided in the radar dataset from each country to use, for example, the information about clutter in the same way. Read more about this in 04-2013 METCOOP MEMO, Ridal et.al [6] where also MET’s quality system PRORAD is shortly described together with the BALTRAD software. The radar-derived parameters used are: reflectivity and radial winds. Quality control has been shown to be very important for radar data. At present, experts are working on both the pre-processing – removing of non-meteorological signals and improved data assimilation schemes.

2.5.3 Job-scheduler system

It is a job-scheduler and queuing system for the common operational NWP which deliver data to an agreed output. The selected ecFlow job-scheduler system handles the common operational runs on both the operational and backup computers. The needed input data (e.g. boundaries, observations and start fields) from both institutes are uploaded to both HPC for different scenarios (e.g. no access to main computer).

The job-system on the HPC had to be taken into account. This has been challenging during the first period of the collaboration due to the overlapping period with national models that are still running, however the latter HARMONIE model at MET Norway and HIRLAM models at SMHI will be turned off when all users have adapted their systems to the new model.

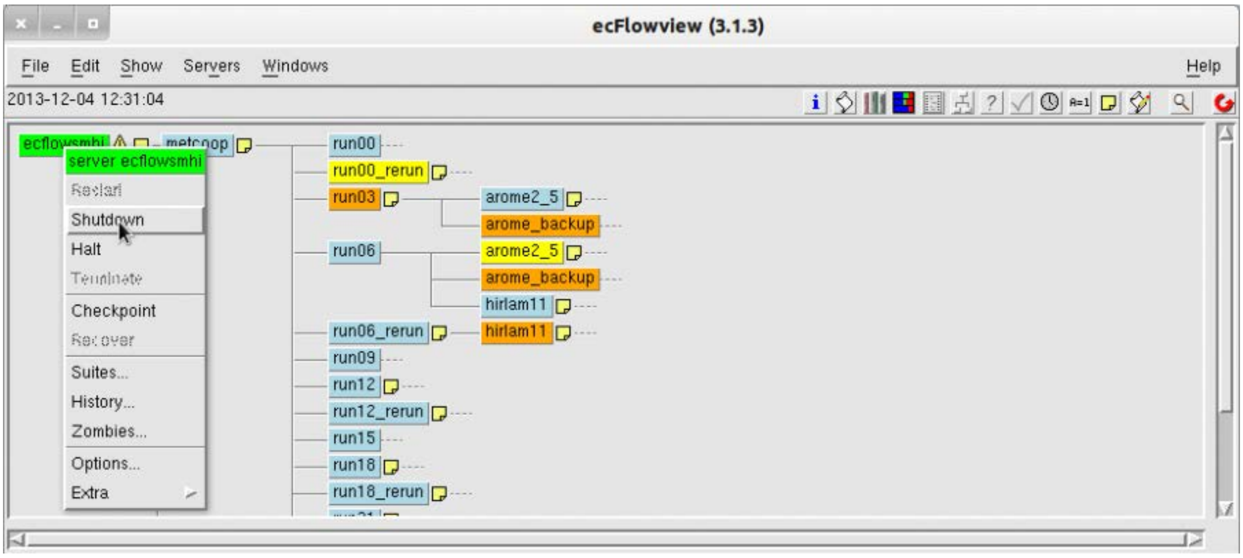

Figure 7. An example from the ecFlow interface, showing the scheduling of the operational model runs.

2.5.4 CPU budget

Some work was done to compute and set up a CPU budget for the new HPC at SMHI (mainly done by SMHI). A decision was taken to budget for a HarmonEPS only with a deterministic control run (with Rapid Updata Cycling). After some preliminary evaluations it has been suggested that an EPS of about 16 members from 2015 could be a realistic goal, given the same model domain and model resolution. Most probably Vilje has to be used to run some EPS members operationally in addition to the new HPC.

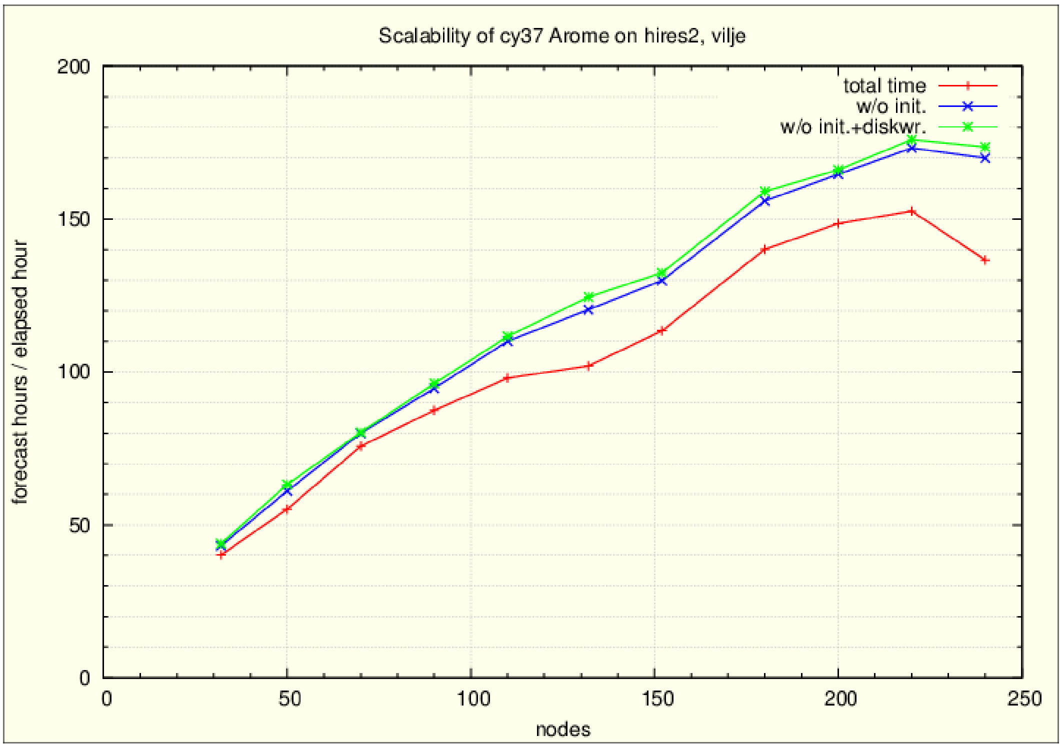

Figure 8. Scalability on Vilje. Elapsed time (y-axis) when using different number of nodes (x-axis) when running Harmonie Arome on the MetCoOp domain called hires2.

A scalability test on Vilje was done to find the optimal number of nodes used to run the model, and also to identify where in the model process optimization was possible in order to reduce the runtime of a single run.

2.5.5 Deterministic model system

In this operational co-operation it was decided to have common operational deterministic models with agreed model domains. The first milestone was to agree about the model-system, and a verification study was done to compare different model-systems in different weather conditions, see Køltzow et. al[5] and it was decided to focus on HARMONIE AROME. It was also decided to integrate the best of the local running HIRLAM versions as one of the deterministic models in the co-operation, because of the operational need for a larger domain and fast updating model. SMHI's HIRLAM 11 based on the 7.1.2 version with some adaptions to version 7.4 as to example for stratiform cloudiness and condensation Rasch-Kristjasson scheme is used and for convection Kain-Frisch KF-eta is used.

Several tests and experiments were run on the HPC with different types of set-up for the HARMONIE AROME model system. Some standard periods were chosen for easier comparison of the experiment results; a windy winter storm, a cold winter period and a rainy summer period. Some experiments were also run on a late warm spring and an early cold spring. The model experiments were: different type of parameterizations (as land friction, convection depths and other aspects of cloud physics), choice of resolution, model domains, blending methods, assimilation of different data types, update cycling (RUC) and other configuration items. A lot of effort was also spent to find the combination of configuration options for an optimal run given the computation power available, and other system-technical tests were run.

In addition MetCoOp did a lot of work due to testing old versions against new versions of the HARMONIE AROME model system, as the code was available for the Hirlam members. This was even more a focus after MetCoOp became a RCR (Regular Cycle of Reference) center with responsibility for HARMONIE Cycle 38. Extensive experiments and tests have been conducted since HARMONIE 38h1 in early 2013 until the beginning of 2014.

It is worth mentioning that much of this model system work has been published as a MetCoOp MEMO see http://metcoop.org/memo

[11] **01/2013**, Karl-Ivar Ivarsson, Morten A Køltzow, Solfrid Agersten. ***Verification of cloud simulation in HARMONIE AROME. A closer look at cloud cover, cloud base and fog in AROME http://metcoop.org/memo/2013/01-2013-METCOOP-MEMO.PDF***

[12] **02/2013**, Per Dahlgren. ***A Comparison Of Two Large Scale Blending Methods; Jk and LSMIXBC***

[13] **03/2013**, Karl-Ivar Ivarsson. ***Verification study of HARMONIE AROME Comparison of the effects of using horizontal resolutions of 2.5 km and 3 km.***

[6] **04/2013**, Martin Ridal, Solfrid Agersten. ***The use of radardata in HARMONIE AROME for MetCoOp. Validation of first results.***

[14] **02/2014**, Karl-Ivar Ivarsson. ***Modification of AROME ICE3 cloud physics, a status report***

2.5.6 Verification

A verification system is used to assess performances and improvements of the model, and to compare different models. This became an important task throughout the project period, and the verification system was prepared to produce frequently statistics of the operational runs – model data compared to observations and the global ECMWF model IFS. The common general system for verification of model-output was chosen to be the WebGraph system which follows the general HARMONIE code system. This was chosen because: the group was familiar with it; several statistical methods for verification were available; it is possible to add more methods and to configure the system in both the experimental and the operational runs. The figures in the MetCoOp MEMO's and the verification results have been created with the WebGraph system.

In Figure 9 an example from the daily verification is shown. This tool is helpful in the operational work because it allows for monitoring the verification result from the models on a continuous basis.

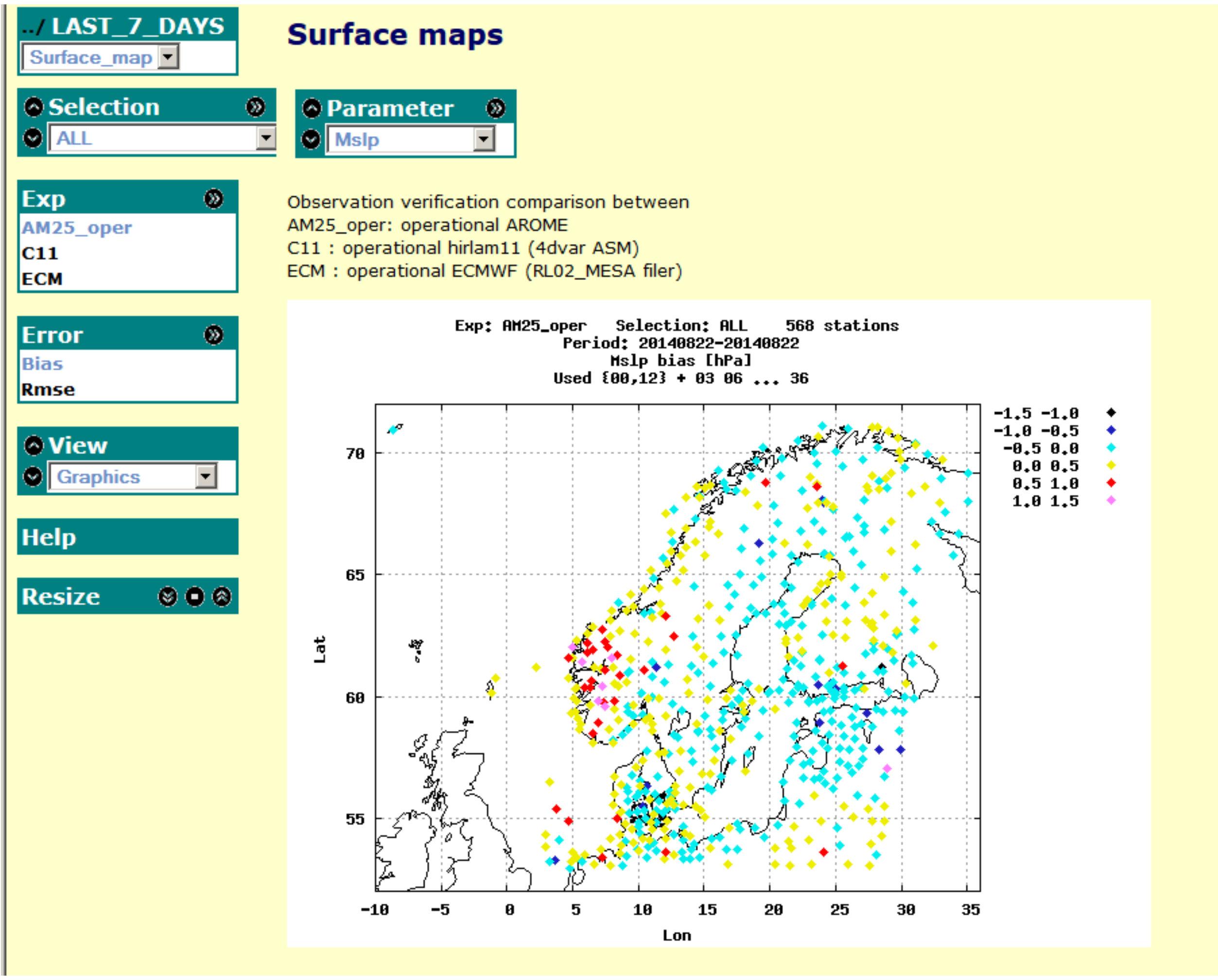

Figure 9 Example from the verification system, comparing daily runs for Harmonie Arome (AM25_oper) Hirlam 11 km (C11) and ECMWF (ECM).

Two verification reports have been published as a MetCoOp MEMO see: http://metcoop.org/memo

[5] **01/2012**, Morten A Køltzow, Karl-Ivar Ivarsson, Solfrid Agersten, Lars Meuller, Dag Bjørge, Ole Vignes, Per Dahlgren, Bjart Eriksen, Martin Ridal, Rebecca Rudsar. ***Verification study HARMONIE AROME compared with HIRLAM, UM and ECMWF***

[15] **02/2012**, Morten A Køltzow, Karl-Ivar Ivarsson, Dag Bjørge, Solfrid Agersten ***Verification study II Supplementary verification of HARMONIE AROME***

2.5.7 Model diagnosis

Monitor the observation usage of the model (Figure 10). Development of this application was an important task during the project period and some methods were tested. An old system was temporary used until it was decided to start with a new and more suitable technology (using R-scripts and a Shiny server). A first version of this new system was released at the end of the project, and it will be further developed to become part of the HARMONIE system. A prototype is available from http://hirlam.org:3838/obsmon2/.

The system for monitoring shows “observation minus background” statistics, observation usage and bias-corrections. The objectives for this system are to detect more easily different kinds of errors and to allow for a quick overview of different observation types, thus allowing for a quick overview of the overall "quality" of the analysis.

There have been difficulties in the diagnostic of precipitation errors due to both displacement and aspect ratio errors on precipitation structures, for example. In addition, the comparison between model fields is not straightforward because of their different resolutions: HARMONIE AROME model (2.5 km) , the HIRLAM model (~10 km) and the ECMWF model (~16km).

Nothing more was done in terms of model diagnosis during the project period, however it will be more important in the operational phase.

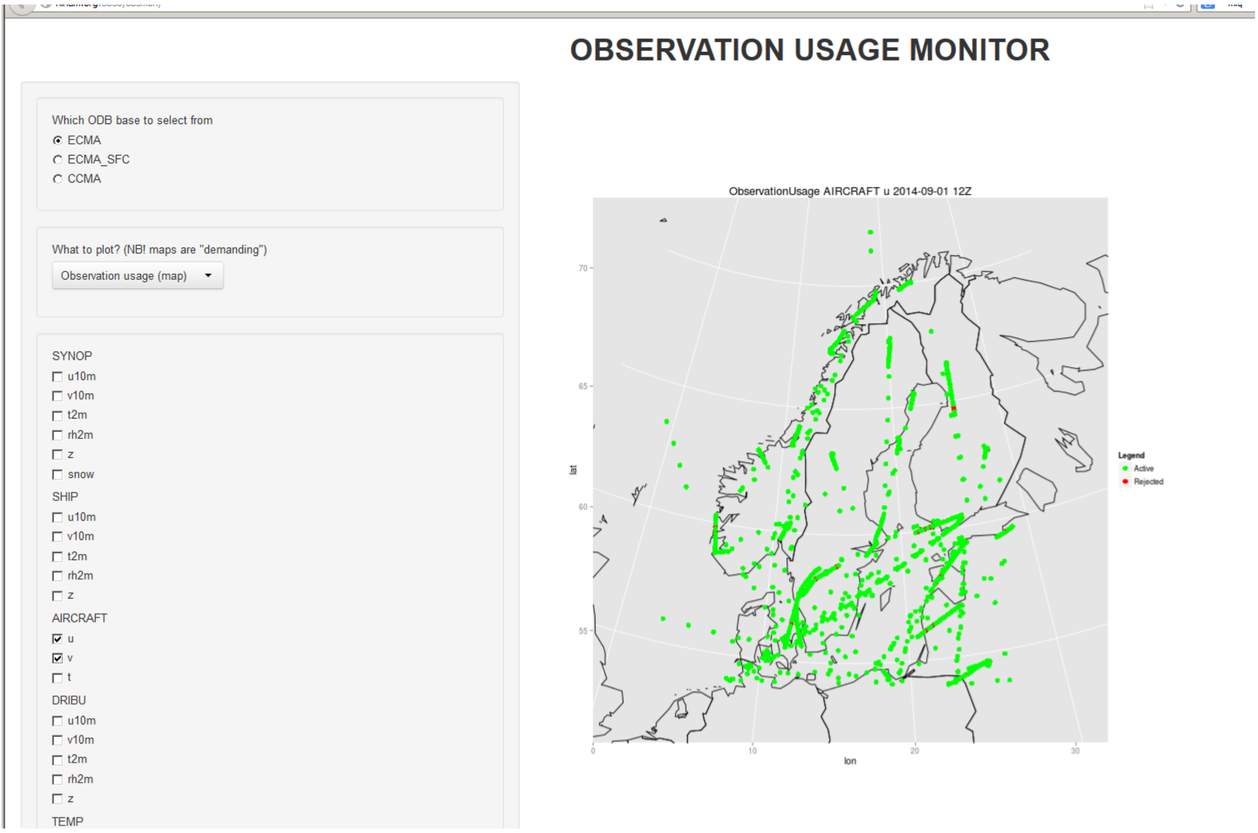

Figure 10 Example from the observation monitoring system.

2.5.8 Ensemble prediction system (EPS)

MetCoOp wanted a common system for ensemble prediction system (EPS), including some post-processing. Already at an early stage it was clear that it was impossible to have established a high-resolution EPS for a common domain before a new HPC was bought by SMHI.

MetCoOp provided a basis for the information exchange between SMHI and MET Norway on both GLAMEPS data production and the subsequent use by the weather-forecasters.

MET Norway had already a local HARMONIE AROME ensemble for a smaller area. Results from this were shared with SMHI in order to let the institutes make experiences with a high-resolution EPS.

2.5.9 Contact with users

The contact with the users of the operational model output to secure downstream effects were kept by both the steering group and the project group. The users are: forecasters, service providers, end-users of model-output, “national operational models”. MetCoOp provided a user survey in order to find out about the requirements for the model system including domain, resolution, prognosis length, time of arrival, parameters in different levels etc. A lot of answers came in and a synthesis of this made the foundation for the decision of the operational model-system in MetCoOp.

A system for information in advance of new versions of the model system was provided and in use, as shown in Figure 14.

2.5.10 System for monitoring

For operations it is necessary to monitor different tasks in order to find out more effectively where incidents or problems appear. A common web-site is set up for MetCoOp, where it is for example possible to:

- Monitor the timeline for the different steps/processes in a model run (Figure 11)
- Monitor the run times for different cycles for both main-runs and the warm backup runs. (Figure 12)
- Monitor the mini-sms at the HPC, with possibilities to find the log for the different steps in the run process
- Monitor observation usage, as described in Figure 10.

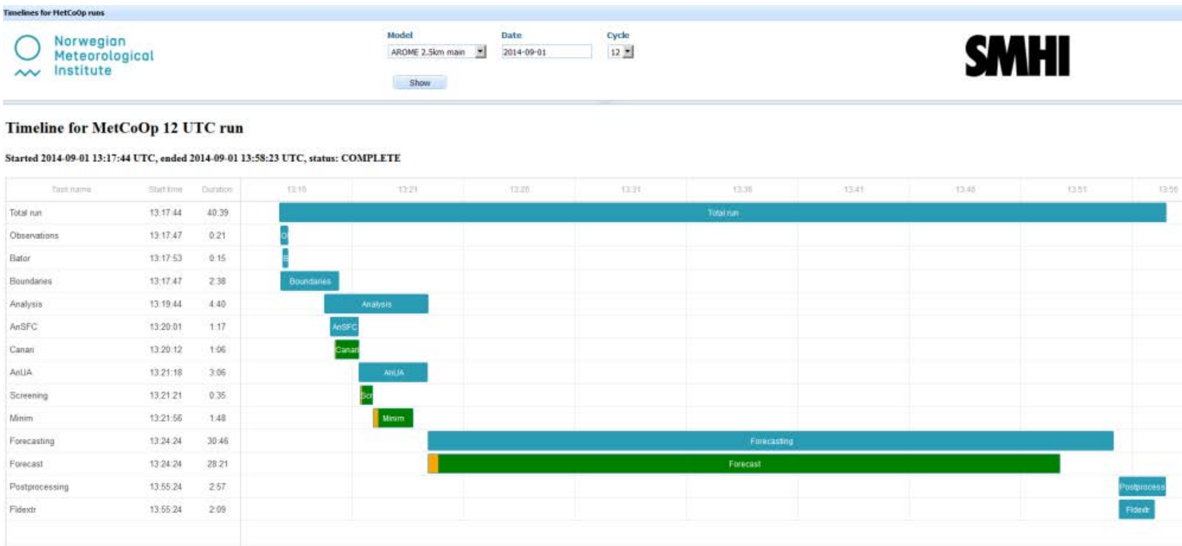

Figure 11 Overview of a model run at HPC, possible to monitor when the model is running at the HPC.

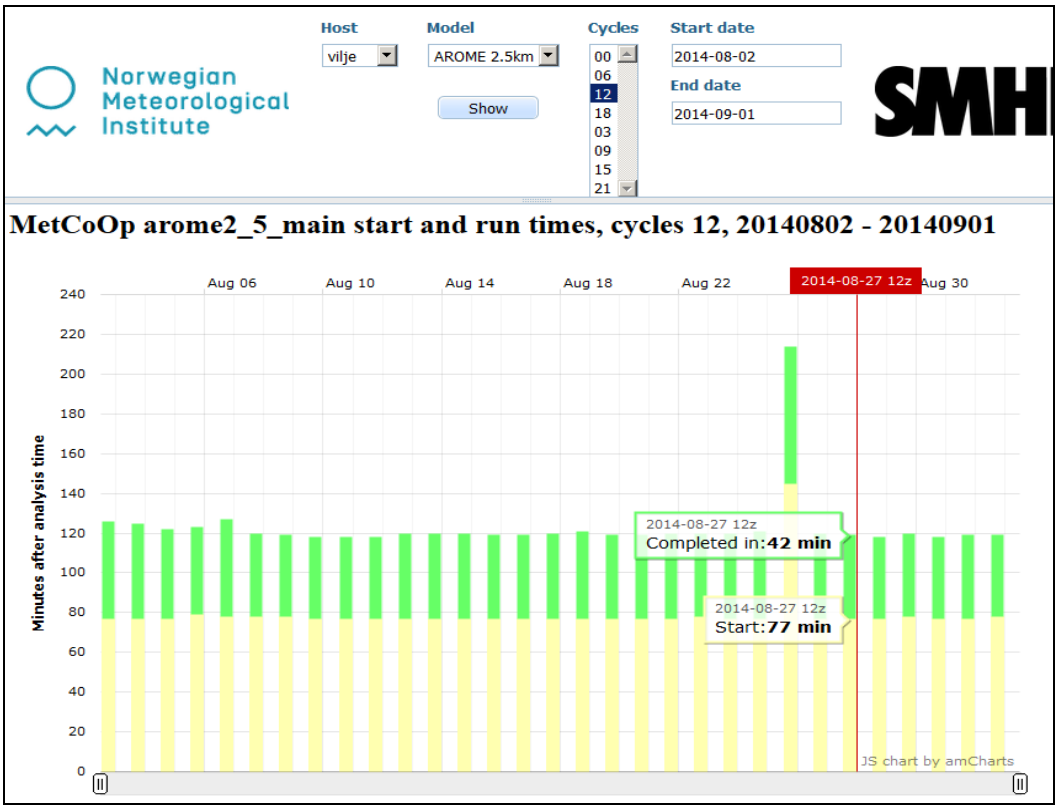

Figure 12 Monitoring run-times. Yellow: waiting for observations (cut-off 75 min), Green: Total run time for 66 hours forecast for MetCoOp domain HAROMINE AROME 2.5 km (42 minutes)

2.5.11 System for feedback (OD/RD)

Monthly meetings between the operational forecasters and the MetCoOp group have been performed both at SMHI (in Norrköping) and at MET Norway (on video including the department in Bergen and Tromsø in addition to Oslo). The meetings were intended to be informal and they provided a place for information, discussions and questions between the groups of forecasters, model developers and NWP operators. The forecasters have shared their experiences and view on using HARMONIE AROME and information about model quality and project progress has been shown. The forecasters will be important in the co-operation for monitoring the model quality. At SMHI they had an "experience log" where the forecasters wrote down every day something about performance of some model parameters from the MetCoOp model. A summarized report about this was provided from one of the forecasters. At MET a list with experiences also existed, but not regularly updated. These experiences are valuable for the model developers and operational group, so the meetings continue also in the operational phase.

One report from the Meteorologists in Norway was conducted; [16] **01/2014**, Bjart Eriksen, Anne-Mette Olsen, Eirik Samuelsen, Solfrid Agersten, Ole Vignes, Karl-Ivar Ivarsson. ***An operational view on HARMONIE AROME for MetCoOp. A case based verification study of "Dagmar" 25-27.12.2011***

When something is wrong with the operational model, the forecasters at each institute should notify the national ServiceDesk as they are used to. It is an operational agreement that MET Norway has the monitoring and service of the system 24/7 in 1.line and SMHI has the responsibility for the on-call employment for IT-related tasks and NWP model issues.

2.5.12 Routines for change

The group established routines for change in model (and model setup) and documentation for different levels of change from small bug-fix (minor) to major version changes (significant). The routines should separate between changes that have meteorological impact and those that have not. It was established a framework for change procedures for testing the meteorological performance of the system, which together with delivery item described in section 2.5.6 “Verification” allows for assessment of quality improvements when updating the model-system.

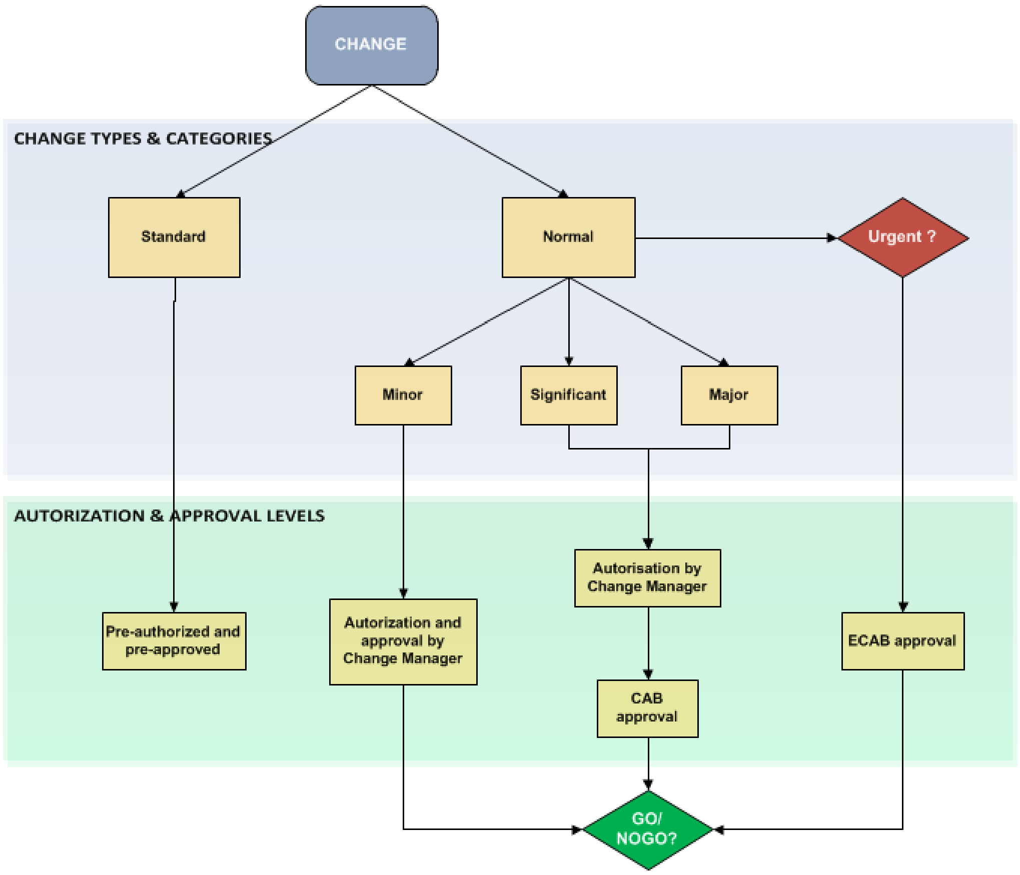

Figure 13 ITIL flow chart for change management.

Change management for scripts in ecFlow was also discussed and agreement with the 1. Line operation team was established for this change procedure.

The ITIL (Information Technology Infrastructure Library) standard was used as a guideline for the change management routines, see *Figure 13*.

A template for a change notification to the users was provided. This template contains type of change, impact for the model result and a description, see Figure 14.

HARMONIE AROME Change Notification

Change valid from: 2013-12-05 kl:09 UTC

TYPE OF CHANGE	SPECIFICATION	RESULT/CONSEQUENCE
Server/IT		
Input data		
Model Update	From cy.38h1b2 to cy.38h1b3	Provides the results on all termins approx. 8 minutes faster than earlier. Slightly better wind and temperature forecasts. For the other parameters almost no differences.
Post-processing		
Other:		

Additional information:

Verification results for summer 2011 is found here:
http://metcoop.met.no/verif/201108_37h11_38h1b1_38h1b2_38h1b3_export/

Verification results for winter 2010 is found here:
http://metcoop.met.no/verif/201011_37h11_38h1b1_38h1b2_38h1b3_export/

Change notification from HIRLAM management: https://hirlam.org/trac/wiki/ReleaseNotes/harmonie-38h1.beta.3#Changesbetweenharmonie-38h1.beta.2andharmonie-38h1.beta.3

The upgrade includes technical fixes in a way that provides faster delivery of the result.

Local change(s) at MET:

Local change(s) at SMHI:

Sender & date:

Ole Vignes and Solfrid Agersten, 05.12.203

On behalf of MetCoOp

Figure 14 Example of a change notification document.

2.5.13 Test-procedures

It is required to have test-procedures for testing the meteorological performance of the system, which together with delivery items (requirements) described in section 2.5.6 on Verification and in section 2.5.7 on Model diagnosis allows to assessing quality improvements when updating model. MetCoOp tested the Meteorological performance of the model-system in high impact weather, as some test-periods were selected:

2011-12; the *Dagmar* storm (2011-12-21 – 2012-01-07)

2010-11; a cold winter period (2010-11-20 – 2010-12-09)

2011-08; a rainy august period (2011-08-12 – 2011-08-23)

Sharing the test-results within the HIRLAM group because of the responsibility as a RCR center helped us to be systematic in the evaluation of the tests.

2.5.14 Archiving system

An archive should make the NWP output accessible for operational- and R&D needs. In October 2012 different strategies for archiving was evaluated and the following recommendation was decided: a shared short term archive in MetCoOp should not be implemented for the time being. The infrastructure subgroup has been unable to identify possible technical solutions that would meet the demands and be cost-effective to implement. Instead, we suggest that each institute archives the data from the joint NWP production in their existing archive solutions. If an event of data loss should occur at either institute, the missing data can be retrieved from the other institute.

MET Norway and SMHI may look into the possibilities for a shared archive solution later, after the MetCoOp project period has ended. A tip may be to look at a solution for a common long term archive, since that may be easier (probably reduced availability requirements) and possibly more cost saving.

2.5.15 Transfer capacity

The transfer of the results (get-jobs) for MET Norway and SMHI is significant. Early in the project it was established an "IT-network group" with persons from both institutes to test and secure the communications and technical solutions and to have a strategy to include safe and sufficient transfer capacity to the operational- and backup HPC-resources for both institutes.

The bandwidth and transfer rates between the parties have been investigated and 100MB lines are applied in all communication lines. It is required and important to ensure 99.9% availability and 99.5% timeliness of the forecast.

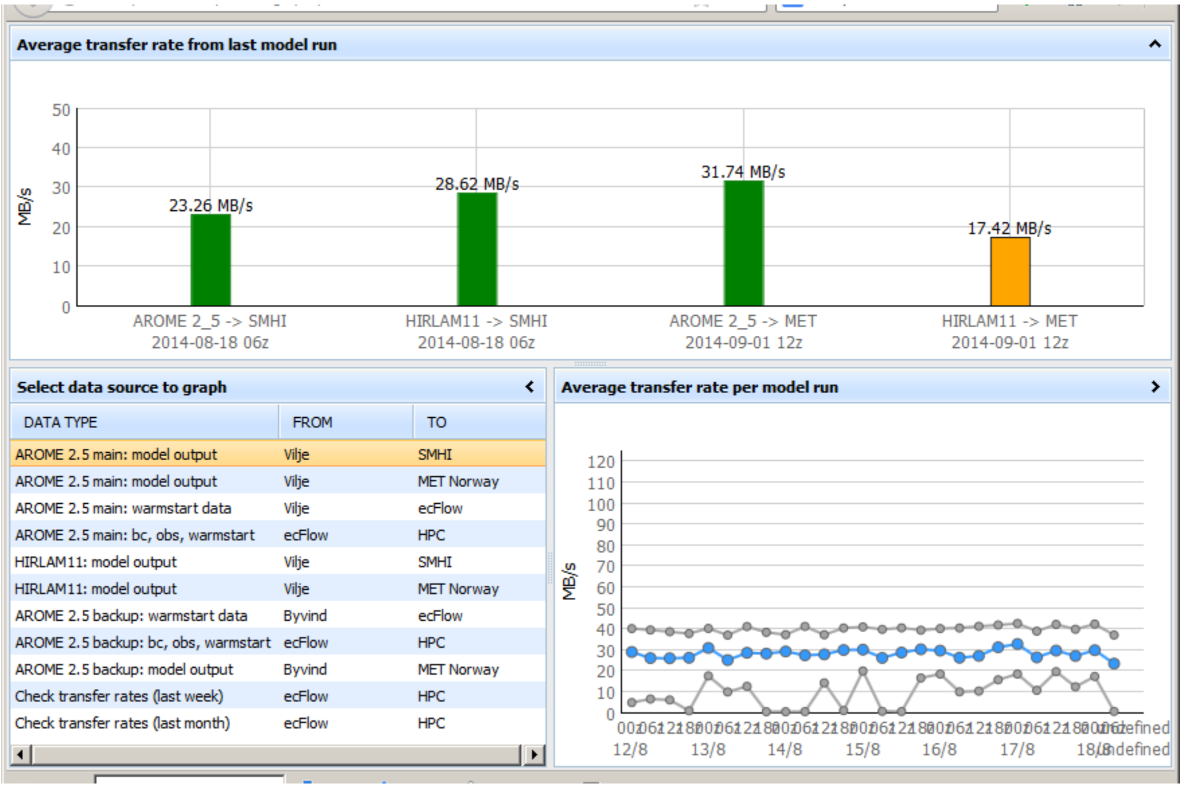

Figure 15 Example from the application monitoring the transfer rates between the two HPC's and the two institutes.

2.5.16 Adapt to new HPC resources

The plan for MetCoOp was that a new HPC should be bought every second year and the prior continues as backup. Every second time the procurement of a HPC should be done in Norway and Sweden. Vilje (in Trondheim) was bought by MET Norway in 2011 and should serve as the main HPC in the project period until 2014. It was problems with the delivery of Vilje, due to new technology etc. A reserve machine was set up for MET Norway and was adapted to in January 2012. MetCoOp adapted to Vilje in summer 2012. Vilje has unfortunately not been stable and a lot of effort and time has been gone in waiting, debugging, restarting, reporting problems etc. This has been a rather frustrating for the project group and has delayed the project, or more precise; more experimental run could have been done i.e. for domain-size, cut-off time, new datatypes etc.

The procurement of the new HPC resource at SMHI was delayed. MetCoOp has been in contact with the HPC partners which currently are NOTUR (Norwegian Metacenter for Computational Science) and NSC (National Supercomputer Centre at Linköping University, Sweden). An initiative to meet all four partners more regularly has been taken to ensure common information and responsibility for the MetCoOp operations.

MetCoOp was planned to go operational from 2014 on the HPC in Sweden, but already in May 2012 this was post-poned half a year because the possibility to get the latest technology and is also post-poned yet another half a year.
There has been a co-operation with NSC to set up a benchmark for new HPC procurements for SMHI. The procurement was planned to be sent in March 2014, and the HPC will be available for test in about one year and accessible for the operations in the second quarter of 2015.

2.5.17 Joint system for procurements

It was assumed that it was required to have a joint system for procurements in the collaboration (other than HPC). It has not been necessary to do any procurement in the collaboration during the project time. Servers have been bought by the institutes and the agreed cost-sharing principles have been used and the balance paid once a year.

2.5.18 Documentation and publishing

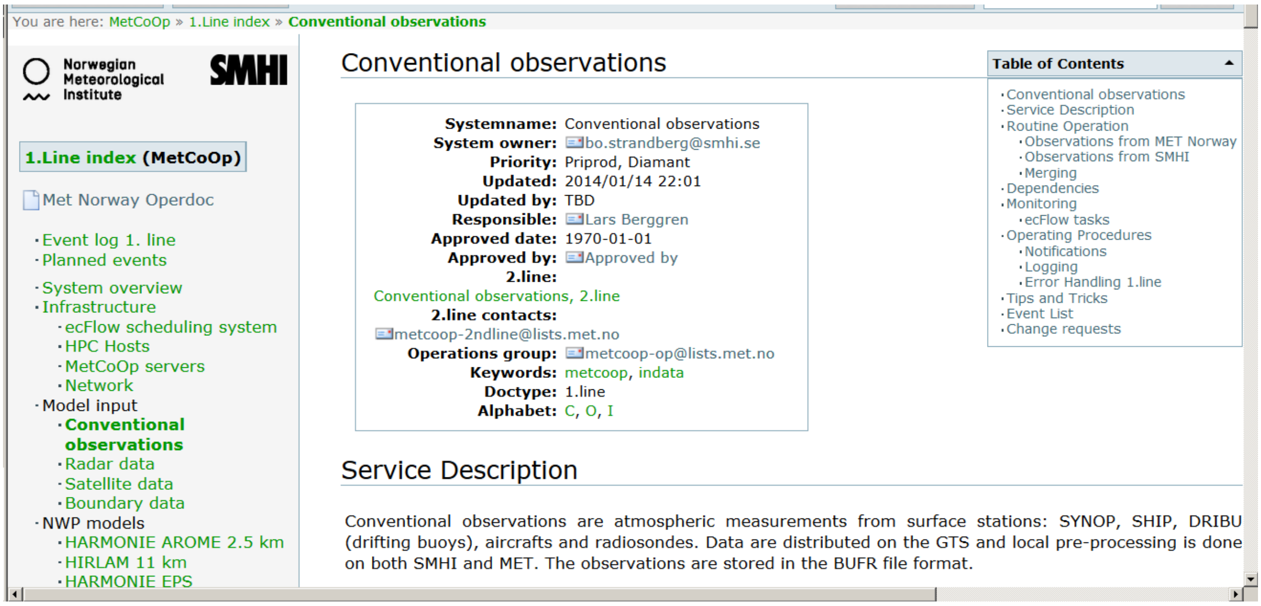

Figure 16 Wiki pages for documentation of the operations for the 24/7 1.line and 2.line

A lot of documentation has been provided during the project period, with sprint reviews more or less every 5th week where status and work were presented and documented. When preparing for the operational phase a dokuwiki page was set up and documentation for the operations were written in English, see Figure 16.

No article from MetCoOp has been published to external journals with peer review as was expected in the beginning of the project, because of the focus on science and development in the project. It was seen as important to document the consecutively results in the project and publish this. There was established a report series for MetCoOp with the ISSN number 1893-7519 titled: METCOOP MEMO, online available at http://metcoop.org/memo . It was developed a template for the report. The reports and work by MetCoOp are licensed under CC BY-ND 3.0: http://creativecommons.org/licenses/by-nd/3.0/deed.en Credit should be given to The Norwegian Meteorological institute and Swedish Meteorological and Hydrological Institute, with use of the logos.

Two reports were published in 2012, four in 2013 and yet another two in 2014.

MetCoOp has been presented in different HIRLAM meetings; All staff conference and meeting with the management group or part of it. MetCoOp has also been presented in different occasions in meetings with users or co-operatives of both MET Norway and SMHI (not presented in the list).

"Meteorological Co-operation on Operational NWP (MetCoOp)" Solfrid Agersten
EWGLAM, Tallin, Estland
10.10.2011. Presentation.

"MetCoOp - Meteorological Co-operationon Operational NWP A Swedish/Norwegian Cooperation"
Solfrid Agersten, Ole Vignes and Morten Køltzow
12th EMS Annual Meeting & 9th European Conference on Applied Climatology (ECAC), Łódź, Poland
10 – 14 September 2012. Poster, http://presentations.copernicus.org/EMS2012-393_presentation.pdf

"Meteorological Co-operation on Operational NWP (numerical weather prediction) between Sweden & Norway" . Solfrid Agersten
Nordic e-Infrastructure Conference, NTNU (Norwegian University of Science and Technology), Trondheim
13.05.2013. Presentation

"MetCoOp - Meteorological Co-operationon Operational NWP A Swedish/Norwegian Cooperation"
Solfrid Agersten, Martin Ridal
13th EMS Annual Meeting & 11th European Conference on Applications of Meteorology (ECAM) , Reading, United Kingdom, 09 – 13 September 2013. Poster, http://presentations.copernicus.org/EMS2013-490_presentation.pdf

2.6 Time and milestones

The project started with a planning period in the spring 2011 and the project had kick-off in August 2011. The project was planned to end at 31.03.2014 at the time when the operational organization for a common NWP production was ready and a new HPC at SMHI was proposed to be available. The latter did not happen due to different circumstances, but did not prevent the operations to start, so the MetCoOp project ended on time.

In the bullet list below the milestones defined in the project are reported on:

- *Decide common model-system, September 2011.*

HARMONIE was decided as the deterministic model to work on in order to make it operational, with a constraint that the model quality should be evaluated so that the final decision of common deterministic model could be taken in October 2012. (steering committee, 06.09.2011)

- *Decide common scheduler system, March 2012.*

MetCoOp did a study of the scheduler systems used at SMHI and MET Norway and other possible solutions, and concluded that the ecFlow system, developed at ECMWF was the best solution. The ecFlow software is the successor of the SMS system, that MET already used. MetCoOp implemented ecFlow on test servers at MET to schedule the model runs at the HPC. For ecFlow in operations virtual servers at SMHI was chosen.

- *Provide verification results, June 2012*

Because of the delay of Vilje all the experiments took time to provide, so the results were not ready before in the autumn. A lot of effort was done to evaluate different models on different weather situations (experiment periods) for the most used weather parameters; air pressure, 2 meter temperature, precipitation, cloud cover, wind direction and speed.

- *Final decision and paper, October 2012*

The final decision about model-system was taken after the evaluation of the experiments above. The verification report was published in the first MetCoOp MEMO (01/2012) with a scorecard that showed that HARMONIE AROME was the best deterministic model for the domain covering Sweden and Norway. No one had experience in publishing verification report in a journal with peer review so this was regrettably not prioritized.

- *Decision about Ensemble Prediction System (EPS) , October 2012*

At this point it should be possible to decide whether or not an EPS system (other than the common EPS in the Hirlam B consortia, GLAMEPS) should be set up to run operationally on common HPC. It was already clear that it was impossible to have established a high-resolution EPS for a common domain before a new HPC was bought by SMHI. MetCoOp provided an exchange of information from SMHI and MET Norway about how GLAMEPS products were produced and used by the weather forecasters.

- *Pre-operational model setup and common benchmarking, June 2013*

The new production model, with the decided domain and resolution and output format and deliverance routines, was available for test from both SMHI (Byvind) and MET (Vilje) in more than 6 months, but as a fully pre-operational system it lasted for approximately 5 months. This delay was due to problems with the infrastructure setup. MetCoOp worked towards a 3dVar data assimilation using different kinds of remote sensing data (conventional observations including soundings and satellite data /ATOVS were included. IASI data and radar data had to be tested more).

- *Final model choice for Ensemble Prediction System (EPS), October 2013*

The common operational EPS has been decided to run on the new HPC in Sweden from Q3 2015, perhaps with some members running on Vilje. This procurement was signalized to be delayed. It was given an overview of what performance would/should be on the next HPC and some requirements for an EPS were outlined. A common HARMON EPS will be a main development task in the time to come to decide resolution, domain(s), number of members etc.

MET Norway provided results from HARMON EPS on 2.5 km from a small domain so that the institutes could gain experience in using that kind of ensemble forecasts.

- *Operational organization, November 2013*

Already in May 2013 a coordination meeting between the IT-operations organizations in SMHI and MET took place. A lot of work designing escalation paths in case of incidents, what tools that have to be available etc. was discovered. Some tools and ways to work were quite different and some decisions were type of short-term decisions and should be evaluated later. It was decided that the IT-directors from SMHI and MET should follow up the co-operation on more areas to secure good solutions in a long time perspective for the common production.
The operational organization for MetCoOp contains both operations and development to mark the importance of a system that is continuously improved. It was requested and designated an operation manager from SMHI and a development manager from MET. Persons to the MetCoOp group were requested and designated in February 2014. For the daily operations MET will serve as first line 24/7, SMHI serve as second line on both NWP model and IT-infrastructure.

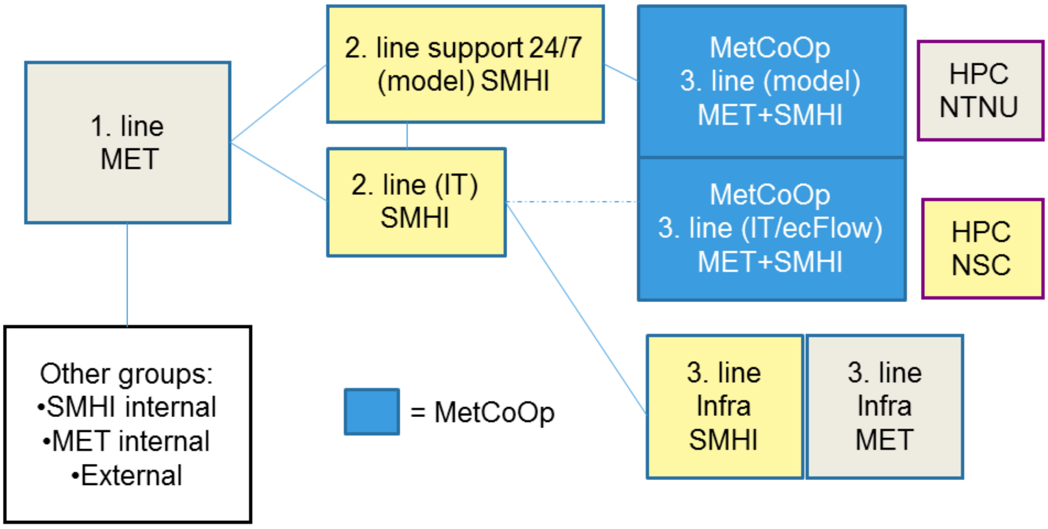

Figure 17 View over operational organization with escalation paths.

- *Set up the operational model and production chain on new HPC resource (SMHI).*

Since this point was not possible to fulfill until the operational start in 2014, the new HPC will be available for MetCoOp in 2015 and this work will be initiated then. MetCoOp has been involved in SMHI’s benchmark process for the procurement of the new operational HPC.

- *Common operations from 31 March 14*

MetCoOp had regular operation of NWP from March 12, 2014 which included both the HARMONIE AROME 2.5 km model and a 11km-version of HIRLAM (a continued version of SMHI's local HIRLAM version). The meteorologists from both institutes had been using the test-version of the MetCoOp NWP model for a long period already by then. At both institutes it was a dialogue with the meteorologists regularly during the project period. It was a gradual process with continuous communication between the MetCoOp project and the organizations on sprint reviews etc. The organizations SMHI and MET Norway had the contact with the downstream users and decided when to start to use the operational NWP results from MetCoOp. At SMHI there was a quite broad user dialogue the last three months. SMHI started parallel production to downstream products more or less the same day and by March 31, the production was based on the MetCoOp NWP production. At MET Norway a local version of HARMONIE AROME cy.37 had been running for almost a year, and the new MetCoOp NWP-forecasts was released downstream use in the mid of May 2014.

2.7 Cost

As a first suggestion 8 persons and a project leader should all be working 50% with the project for 2.5 years, which means 4.5 FTE (full-time equivalent) per year. This estimation was followed and the involved parties had a small invoice for every year to pay for the overhead, according to the common agreement. There were some knowledge transfer (from soon retiring people) during the project period, so the actual hours used was some more than planned. In some periods more time was spent on research and on management. In addition the project needed some effort from people outside the project. Total reported time spent on the project by the team and project leader in 2012 were 8436 hours and in 2013 were 8638 hours That means approximately 5.5 FTE per year during the project period which lasted for about 2 years and 7 months. The project time was extended with three months because of the initial plan of starting the operational phase on a new HPC in Sweden. This plan was changed after a while, and the operational phase was started on the HPC in Norway, but the end-time of the project was kept.

The project group travelled to the other country (Sweden and Norway alternately) almost every month ie. about 8 times a year. That means that every project member travelled at least 4 times a year during the project period to meet the project team and work together. The project leader travelled more frequently and had about 10 travels a year to the other country. All trips that were planned, were carried out and did not exceed the budget.

There were facilitated approximately once a year workshops outside the organizations including lunch and another environment. The project team was also invited to dinner one or two times a year. The budget included a study trip to another institute in Europe, but this trip was never conducted.

Some common tools to share information- and/or desktops, video equipment or other communication facilities were already available for the project team and no investment was required.

The cost of the project was equally shared between the parties, SMHI and MET Norway. For more details see [1] chap. 6.3 in 'Report on operational Co-operation between SMHI and met.no on NWP 2010-05-31'.

3 Project progress

Project management was done with use of Scrum, an agile method (Scrum: “A rugby term used when members of the rugby teams form a circle to get the ball back into play.”), see *Figure 18. Description of the Scrum methodology*. The Agile manifesto was assumed to be suitable for this kind of project in order to meet the vision, to provide good communication through the borders, and to hold focus on gaining progress in small steps achieving velocity in the project, since the project period was nearly 3 years. A Scrum coach was hired to hold a lecture about the project method, since most of the team members did not know Scrum. The project methodology was used in a way that the team self-managed,took decisions collaboratively and was collectively responsible for sprint delivery. They solved problems,made progress and seemed to have fun together.

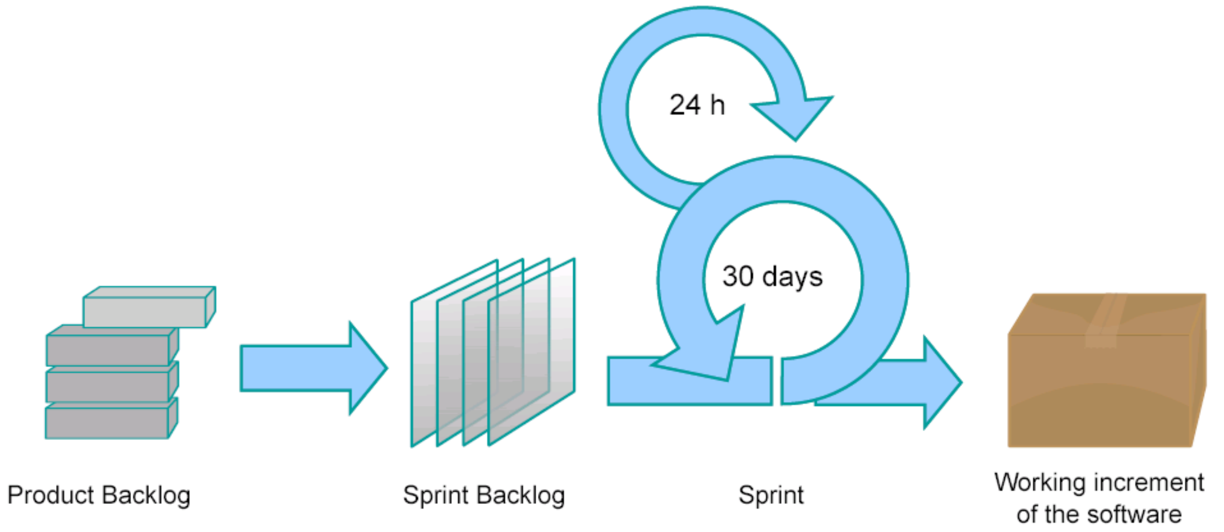

Figure 18. Description of the Scrum methodology.

In Figure 18 the process of Scrum is shown; planned tasks in the sprint backlog, taken from the product backlog in the requirements, are taken into the to-do-list in the sprint (30 days). At every working day the status is assessed on the tasks answering the questions; “What did you do yesterday?” “What will you do today?” “What are your impediments?” The result of these steps is to gain progress. After every sprint there was a short retrospect where the group could talk about different aspects of the team-work in order to figure out what was “good and bad” to correct the direction.

A review was held after every sprint where the achievements and results were presented for forecasters, scientists and others at the institutes that were interested. The reviews were held at SMHI and MET Norway every other time and were streamed (live).

After the review the project group planned the next sprint. It was needed to identify the workload for the team members. The requirements acted as the main guidance for all tasks defined in the Scrum project.

A web-based tool called RedMine, hosted by SMHI, was used to plan sprints and specify tasks and follow the workflow. Wiki pages, hosted by MET Norway were used to share the requirements, user stories, documentation etc. regarding the project.

All persons in the project worked about half-time with MetCoOp and worked every Wednesday and Thursday, which also were the days where the group met half an hour for a Scrum -meeting on video (as a “daily standup”). The team worked together in a project room at SMHI and at MET Norway. The project leader (from MET Norway) served as the project owner, and coordinated the work. She also acted also as the Scrum -master (together with a manager from SMHI) and facilitated for the work to be done, planned meetings and planned the work ahead together with the team and provided basis for decisions when needed.

The steering committee was the main decision body and acted as the principal and the project leader as the contractor. The project employed the Tieto Enator Practical Project Steering (PPS) model as the steering model and followed its basic decision point model which covers the basic lifecycle of a project. The Scrum project method required a light weight and iterative approach to the decision point (DP) model. The decision point DP6/5 “Decision to accept project delivery and decision to continue project” passed after each sprint during the project period. The project leader/ product owner recommended approval of the sprint deliverables to the steering committee.

The project team followed the project plan with a parallel focus and work flow on some of the different mile-stones (see 2.6 Time and milestones and requirements reported in 2.5 of requirements, delivery items) and worked towards the settled goal to finish the project in time. When the project experienced lack of people to implement solutions at the institutes, there was a process to go to the leaders to force them to prioritize people to work with the MetCoOp project.

4 The experience of the organizations and the participants

4.1 The experience of the organizations

In March 2014 the relevant users and representatives at the institutes were asked about their experiences of the project. Not all departments answered and especially MET Norway (shortened MET) had very few responders (possibly because of the earlier introduction of the high resolution model HARMONIE AROME in operations at MET Norway). The questions and most of the answers are outlined in this section.

The feedback shows that there has been an open project with possibility to read about or listen to the monthly sprint reviews as status. The co-operation has been positive both for the IT- and research areas. The resulting model-system and common operations are welcome. There are valuable thoughts about future co-operation both in the field of HPC, research, forecasting and user-focus on how to apply the results.

4.1.1 Impact on your department/unit? Pros and cons?

“The project has been very transparent. Since the project started, the project has invited all departments within both institutes to monthly sprint reviews, sharing the progress of the project, introducing the next steps and encouraged dialog and input. The sprint reviews have been appreciated and well attended.”

“Both institutes have been, in a good and generous spirit, sharing knowledge and exchanged experiences towards the joint goal.”

“The dialog and co-operation between the IT departments at SMHI and MET have worked well.”

“A frequent contact with NSC has been necessary and has been working out very well.”

“Information from the project to the department representatives in both institutes has been shared through sprint reviews, internal web sites and other working groups/forums. However, the information transfer from some of the department representatives to the rest of their departments/units has not always worked out as expected. Some co-workers feel that some of the information did not reach them.”

“The result of the project has given the meteorologists a powerful tool to increase the understanding of the present weather and increased the ability to forecast extreme weather.”

“Becoming more active in the operations (probably due to the usage of HARMONIE) and by increased research communication with MET. It was good that MetCoOp was a well-funded focal activity at SMHI and MET.”

“To be able to use the new features effectively we have to be willing to make changes in both the way we design our product as well as the way we work with our forecasts.

Information regarding upcoming changes in the model through different forums is very important when the project turns operational.”

4.1.2 How has your department been involved in the project?

“The department has been active in the discussion on the domain, continuation with EPS, usage of observations, structure function generation and system work. The HIRLAM work done for HARMONIE became closer, because HARMONIE will be used operationally. The direct inclusion of two researchers in the MetCoOp project also involved the others by discussion etc.”

4.1.3 What do you expect as effects of the project and co-operation for the future?

“An extended Nordic NWP and HPC cooperation in the future.”

“We will continue exchanging knowledge and experiences and saving both time and costs.”

“Expectation of a close collaboration on aspects of NWP, eg. inclusion of new observations to operations, statistical post-processing. Furthermore, research proposals will be organized in closer communication between SMHI and MET.”

“Extend the cooperation on how to apply the results.”

“Good information and the possibilities to take care of input from the organizations will increase the quality factor and the usage of products.”

“MetCoOp will give us opportunities to improve our warnings and extreme weather forecasts.”

4.2 The experience of the project participants

A project evaluation by the project team started with a brainstorming phase. Thereafter the identified tasks were structured and analyzed to find causes for the most important problems and successes. A technique including “fish bone” diagrams was used to summarize this; an arrow as the fish (*success or problem*) was drawn with the fish bones as the *causes*.

Even though the project mainly was experienced as positive, there were some problems to be addressed. The main frustration in the project was the lack of IT-resources from one of the organizations. Because of the decision to let this organization host the IT-infrastructure this became a bigger issue than expected due to the slow communication on important IT-tasks, the different way to organize the infrastructure, process for requesting permissions etc. This problem was pointed out to be the root cause to why the pre-operations got a shorter stable production period than expected and that a residual list of work in progress exists for the operational group after the project phase.

An issue was also about the Met Norway HPC; the delayed delivery and the occasional stability problems. The consequence was frustration, loss of work-hours for the project-group and scientists. In MetCoOp some more experiments could have been run and the pre-operations could have been run for a longer period with more stable operation.

The Ensemble Prediction System that was planned to run in the co-operation has to wait until the new HPC at SMHI arrives, which has been postponed from Q1 2014 to Q2 2015.

Another problem addressed was the lack of communication with the steering-group in the initiation phase of the project. This resulted in unnecessary uncertainty about the model-choice and establishment of the operational group. This evaluation revealed that these decision processes could have been solved more easily with direct contact between the experts and the decision makers. The co-operation got a shorter handover period to the operational group, for testing, checks and robust pre-operations before the projected ended.

The last issue noted was that the project could have had more progression if there were more workshops and more discussions about operational issues. To see more co-operative effects in areas uncommon for the people in the other country (as ecFlow and Vilje for SMHI, prod/test/development It-infrastructure and Ester for MET Norway), the relevant groups should have met more frequently.

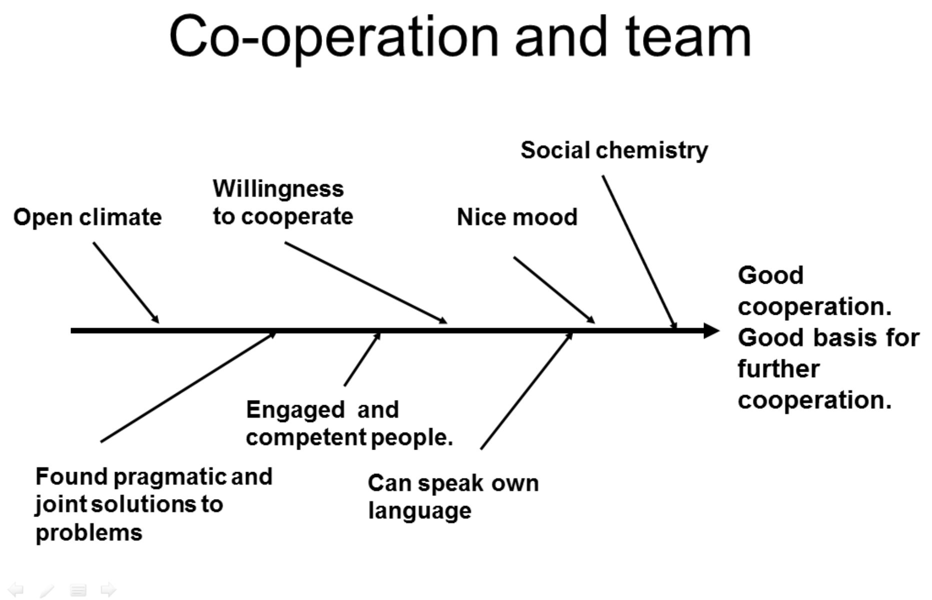

Figure 19. The success factor "co-operation and team" gave the effect of a good cooperation and a good basis for further cooperation. The "fish-bones" show the causes for this experienced success.

The project analysis showed some main reasons why the project finished in time and was experienced as a success. The main reason why the project delivered on time and that the group experienced the project as good was the project method, an agile approach; with frequently meetings (Scrum-meetings) and delivery (sprint-reviews). Good planning and organization with even workload and close follow up gave progression in the work. The project was realistically planned (2.5 year) and well anchored in the organizations. The team consisted of committed people with different skills that worked well together. They worked focused towards the goal to facilitate for common NWP operations. The co-operation in the project was good and is found as a good (and necessary) condition for the further operational co-operation.

Positive spin-off effects that were found were e.g. learning, more co-operations between different groups, within the organizations and between the organizations. MetCoOp MEMOs were published and the operations got useful tools to follow the common NWP production. Meetings and co-operation between the NWP developers and scientists were initiated and will continue the development towards the vision to have the best weather model forecast for both countries and adjacent areas.

5 Experiences and recommendations

From the project evaluation, delivered in March 2014 to the involved parties, experiences and recommendations could be derived. As reported above in chapter 4.2, the project evaluation suggested improvement and success-factors. To summarize it is experienced that:

- Plan early enough and work with anchoring of the project in the organizations
- Finding what competence is necessary and involve people with this competence
- Work together in team across disciplines (and countries)
- Give people responsibility and point out clear goals
- Regular meetings on video as well as physical meetings and workshops are necessary
- Continuous deliveries and focus on the right tasks gave progress
- Do not underestimate decision processes that involves users and/or decision makers at the involved institutes
- Necessary to have an early focus on IT-technical solutions and prepare for the implementation phase; it will probably be more complex and some unforeseen issues might happen.
- Organizational issues take a lot of effort and time.

6 Planning templates, key numbers

The Scrum-methodology was adapted to the framework to co-operate between countries and organizations and also between different disciplines. Burndown-charts, story points and Scrum terminology were not used consequently in the project, but used as described in chapter 3 Project progress. The project was not an IT-project (with small deliveries of working program-code) and not a research project, but gained a lot of working agile and using the main ingredients of Scrum (as described in chapter 4.2 The experience of the project participants) e.g; daily standups, planning in short-term (4-6 weeks ahead), delivering after every sprint. The main tool that was used for task planning and following the progress in the sprints and during the project was RedMine. Wiki-pages were used to write documentation, plan meetings and publish the presentations from the Sprint Reviews etc. It was found to be a good practice to travel every other sprint to the other country and to stay there for a couple of days to work together. Key numbers can be found in chapter 2.7 Cost.

7 References

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[2]	Agreement governing Operational co-operation on Numerical Weather Production	2011-09-20 https://wiki.met.no/_media/nwp/final_agreement-smhi-metno.pdf
[3]	Meteorological Co-operation on Operational NWP (MetCoOp) Project plan	2011-08-24 https://wiki.met.no/_media/nwp/project/plan/metcoop_projectplan_final.pdf
[4]	Project directive for MetCoOp	2011-08-24 https://wiki.met.no/_media/nwp/project/plan/metcoop_project_directive_final.pdf
[5]	"Verification study HARMONIE AROME compared with HIRLAM, UM and ECMWF", Morten A Køltzow, Karl-Ivar Ivarsson, Solfrid Agersten, Lars Meuller, Dag Bjørge, Ole Vignes, Per Dahlgren, Bjart Eriksen, Martin Ridal, Rebecca Rudsar.	MetCoOp MEMO **01/2012** http://metcoop.org/memo/2012/01-2012-METCOOP-MEMO.PDF
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[14]	“Modification of AROME ICE3 cloud physics, a status report” Karl-Ivar Ivarsson.	MetCoOp MEMO **02/2014**, http://metcoop.org/memo/2014/02-2014-METCOOP-MEMO.PDF
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8 List of figures

ANNEX 1.

Verification scorecard for MetCoOp – details of cy.38h1b3 relative to Cy.37h1.1 and ECMWF

Karl-Ivar Ivarsson (March 2014, the results are shared in SMHI and MET Norway and between the HIRLAM/ALADIN countries but not published):

In this summary, we attempt to arrive at an overview on the meteorological status of the HARMONIE-38h1. This summary was provided to the HIRLAM management from MetCoOp as RCR for cycle38, and it justifies the decision to upgrade from cycle37 to cycle38. Extensive experiments and tests have been conducted since HARMONIE 38h1 in early 2013 until the beginning of 2014.

The complexity is due to:

1. different behavior in different domains/seasons/climatologies;
2. evolving versions of 38h1-trunk;
3. lack of comprehensive all-inclusive score-card.

The statistical scores used in this summary are:

RMSE= Root Mean Square Error
BIAS= systematic error
FB = Frequency BIAS (FB)
ETS= Equitable Threat Score ETS8= ETS 8 m/s threshold, ETS14= ETS 14 m/s threshold, ETS0.3= ETS 0.3mm/12hr, ETS3= ETS 3.0 mm/12hr, ETS10 = ETS 10 mm/12hr.

Verification scores used in this evaluation are the same as described in the first verification report [5]: http://metcoop.org/memo/2012/01-2012-METCOOP-MEMO.PDF

The scorecard assigns skill levels of the HARMONIE model candidate in terms of relative performance compared to other models available at the institutes.
Parameters that are considered:

- land surface temperature at 2 m (T2M),
- wind speed in 10 m (10-m wind),
- precipitation for 12 hours (Prec 12 h)
- relative humidity at 2m (RH2M),
- total cloud-cover (TCC)

Experiment -name: **AM25KIZ/AM_Hires2T** * Cy37h1.1 * CANARI OI-Main * 3DVAR with conv. observations * Reference version with CROUGH = Z01D * Boundary frequency: 3h * Forecast length: 48h * At 00 and 12 o'clock	Experiment -name: **LM38h1b3/ OV_38h1b3_ref** * Cy38h1beta3 * CANARI inline SODA * 3DVAR with conv. observations * Reference version with CROUGH = Z01D * Boundary frequency: 1h * Forecast length: 48h * At 00 and 12 o'clock

The periods used in the experiment are the same as in the first verification report [5], so more detailed information about the weather situation in the periods can be found there.

2011-12; the windy Dagmar case (2011-12-21 – 2012-01-07)

The detailed verification plot can be found here (only available for SMHI and MET Norway): http://metcoop.met.no/verif/201112_37h11_38h1b3_ECM_export/

2010-11; the cold winter (2010-11-20 – 2010-12-09)

The detailed verification plot can be found here (only available for SMHI and MET Norway): http://metcoop.met.no/verif/201011_37h11_38h1b3_ECM_export/

2011-08; the rainy august period 2011-08-12 – 2011-08-23

The detailed verification plot can be found here (only available for SMHI and MET Norway):

http://metcoop.met.no/verif/201108_37h11_38h1bh3_ECM_export/

Summary:

The differences between the HARMONIE AROME versions 38h1b3 and Cy.37h1.1, as shown in the scorecard (Table 1) are:

- 2-m relative humidity: *Generally better with cy 38.*
- 10-m wind: *Small difference in forecast quality.*
- Precipitation and total cloud cover: *Generally the same quality or marginally better with cy 38.*
- 2-m temperature: *Somewhat better in summer, but somewhat worse in winter. The reason for the degradation in winter is a more pronounced negative bias.*

The differences between HARMONIE AROME 38h1b3 and ECMWF as shown in the scorecard (Table 2) are:

- 2-m relative humidity: *Generally the same quality.*
- 10-m wind and precipitation: *Better forecasts with AROME Cy 38 than with ECMWF*
- Total cloud cover: *Better forecasts with ECMWF than with AROME Cy 38*
- 2-m temperature: *AROME cy 38 is clearly better in summer, but somewhat worse in winter.*

See also the verification scorecard underneath for HARMONIE AROME (38h1b3).
Explanation of the symbols:

++	indicates that **38h1b3** is clearly better than the compared model.
+	indicates that **38h1b3** is better than the compared model.
0	indicates that **38h1b3** is similar in quality to the compared model.
-	indicates that **38h1b3** is worse than the compared model.
--	indicates that **38h1b3**is clearly worse than the compared model.

38h1b3 vs 37h1.1	Domain	Norway			Sweden			Whole		
Param:	statistic method	2011 - 08	2011-12	2010 -11	2011 -08	2011-12	2010 -11	2011 -08	2011-12	2010 -11
Rh2M	RMSE	+	++	+	+	++	++	+	++	++
10-m wind	RMSE	+	0	0	+	0	0	+	0	0
	FB	-	0	-	0	-	0	0	0	0
	ETS 8	-	0	0	0	0	0	+	0	0
	ETS14		--	0		0			-	0
Prec 12h	BIAS	0	+	0	+	0	0	0	0	0
	FB	0	0	+	0	0	0	0	0	0
	ETS 0.3	0	0	+	+	0	0	+	0	0
	ETS 3	0	0	-	0	0	0	+	0	0
	ETS 10	+	0	++	0	0	-	0	0	0
T2M	ETS	0	0	0	+	0	0	0	0	0
	RMSE	0	0	0	+	-	-	+	-	-
TCC	BIAS	0	0	0	0	0	-	0	0	0
	FB	0	0	0	0	+	0	0	0	0
	ETS	0	0	0	+	+	-	0	0	-

Table 1. Scorecard showing differences between the HARMONIE AROME versions 38h1b3 and Cy.37h1.1

38h1b3 vs ECMWF	Domain	Norway			Sweden			Whole		
Param:	statistic method	2011-08	2011-12	2010-11	2011 -08	2011 -12	2010 -11	2011-08	2011-12	2010-11
Rh2M	RMSE	0	+	0	-	0	0	-	+	+
10-m wind	RMSE	+	+	++	++	+	++	++	+	++
	FB	-	0	0	+	+	+	+	0	+
	ETS 8	-	0	**0**	0	+	+	+	+	+
	ETS14		--	--		+			-	-
Prec 12h	BIAS	-	++	+	0	-	0	-	-	+
	FB	++	+	++	+	0	0	++	+	+
	ETS 0.3	+	+	++	+	+	+	+	0	+
	ETS 3	0	0	0	0	0	+	-	0	0
	ETS 10	-	0	++	-	+	0	-	0	0
T2M	ETS	++	+	+	0	-	-	+	0	-
	RMSE	++	-	0	+	-	-	+	-	-
TCC	BIAS	0	-	0	-	-	--	-	-	-
	FB	--	--	--	-	0	--	-	-	--
	ETS	--	-	-	-	-	--	-	-	--

Table 2. Scorecard showing differences between the HARMONIE AROME version 38h1b3 (2.5 km resolution) and ECMWF (IFS, global model ~16 km resolution)

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