1 hourly Rapid Update Cycle

Detailed LACE DA action and challenges for 2015 and beyond

written by Mate Mile

1. Introduction
2. Examples and existing systems
3. Challenges
4. Plans for actions
5. References

Introduction

Towards mesoscale NWP models and with increased horizontal and vertical resolution, the accuracy of initial conditions becomes even more crucial, hence smaller scale processes of the atmosphere have less and less predictability (*Fabry and Sun*, 2009). The Rapid Update Cycling approach with increased analysis frequency in the assimilation cycle aims to involve more observations with reduced representativity error in time. It is assumed that the more observations we consider for the update of the model state, the better initial conditions we will get when starting a production forecast from the assimilation cycle. Practically the conventional observations (except radiosonde reports) are usually available with higher temporal frequency and also non-conventional remote sensing observations are available in a very timely manner, almost immediately after analysis time, which allows to keep an operational observation cut-off time rather short, and thus to provide NWP forecasts with an early delivery. The RUC approach is effective with sequential data assimilation schemes like optimal interpolation, nudging and 3DVAR. However such sequential assimilation schemes are not usually taking into account forecast error covariances in time which would be a very important feature of a mesoscale data assimilation system. On the other hand more advanced data assimilation algorithm like 4DVAR has also limitation on mesoscale. Hence 4DVAR algorithm requires repeated sequential runs of a linear (TL) and an adjoint model (AD), it is difficult to apply such method on very high resolution and parallel computer architecture. In conclusion the RUC assimilation cycle can provide effective, fast method and early delivery initial conditions for mesoscale NWP and nowcasting purposes.

Examples, existing RUC systems

RUC and Rapid Refresh (RAP) at NCEP:

At NCEP the first version of Rapid Update Cycle based on 3 hourly cycle was implemented operationally at 1994. The **hourly RUC** became operational in April 2002 where assimilation method 3DVAR was applied with observations from Rawinsonde, Wind profilers, RASS virtual temperature, VAD winds, Aircraft reports, Surface and Bouy, satellite derived observations from GOES, SSM and GPS and occasionally dropwinsondes. Horizontal resolution was 20km and special hybrid isentropic-sigma vertical coordinate was used which provides sharper resolution near fronts and the tropopause (*Benjamin et. al.* 2004.).
The NCEP's RUC system has been upgraded to **Rapid Refresh (RAP)** assimilation/modeling system in May 2012 which system includes a so called Grid-Point Statistical Interpolation (GSI) scheme using advanced variational data assimilation algorithm. In RAP, GSI is able to perform hybrid analysis i.e. background errors are constructed from global GFS-EnKF ensemble forecasts (ensemble B) and climatological WRF runs (static B). GFS-Ensemble resolution is 3 times and analysis resolution is 2 times coarser than the RAP background. The hybrid 3DVAR approach brings clear improvement compared to only 3DVAR based RAP. The data assimilation system of RAP has also specific analysis

features like Cloud and Hydrometeor analysis, Digital-Filter based reflectivity assimilation (DDFI, *Huang and Lynch,* 1993.) and special treatment for surface observations (*Presentation from NCEP webinar,* 2014).

NWP based nowcasting system at UK MetOffice:

A so called Nowcasting Demonstration Project (NDP) has been set up to produce more accurate and timely NWP forecasts for nowcasting purposes and for Olympic Games 2012 London. In the frame of NDP an advanced hourly cycling NWP system has been developed which combines **4DVAR** data assimilation method running on 3km horizontal resolution and UK Model 1.5km producing 12 hours long forecasts started from hourly analyses. The NDP 4DVAR uses the following observations: wind observations from Doppler RADAR and windprofiler, satellite radiances from Meteosat SEVIRI channels, hourly 3D moisture derived from cloud observations, AMVs and SYNOPs. The 4DVAR employs hourly assimilation window and 45 minutes cut-off time. Beside 4DVAR technique, RADAR derived rain rates, available every 15 minutes are assimilated with **latent-heat nudging** during the first hour of model integration (*Jones and Macpherson,* 1997). More information about the project can be seen on NDP webpage of MetOffice (*http://www.metoffice.gov.uk/research/news/nowcasting-demo*).

Developments of HARMONIE RUC at Danish Met Institute (DMI):

A 3 hourly updated mesoscale data assimilation system based on HARMONIE 3DVAR has been developed at DMI. The Danish RUC assimilation cycle has special “asynoptic” organization which enables even more earlier delivery of forecast products to forecaster and end users.
A new nowcasting system is also under development with hourly updated assimilation cycle and with a combination of 3DVAR and a **new DMI nudging scheme**. Nudging scheme is assimilating clouds and hourly precipitation analysis derived from RADAR in a conceptual approach. In this nudging scheme an additional nudging term is added to divergence in the mass continuity equation in order to trigger convection during the very short forecast ranges. (*Korsholm et al.*, 2014).

LAPS system at NOAA Earth System Research Laboratory:

The Local Analysis and Prediction System (LAPS) consists NWP data assimilation and nowcasting applications to give very frequently updated, very fine scale analyses using Weather Research Forecast (WRF) or other models (*Toth et al.,* 2014). The most important feature among the developments of LAPS is a variational method based on **Space-Time Multiscale Analysis System** (STMAS) (*Xie et al.,* 2011.). The STMAS iterates sequentially the variational analysis starting with larger scales and ending at the smallest resolvable ones. However the system works efficiently, further challenges have to be considered concerning the background error covariances and balance operator on different iteration steps of the STMAS i.e. different scales.

Basic characteristics of Meteo-France's AROME RUC:

AROME 3DVAR RUC is operational at Meteo-France with 3 hourly analysis frequency and 2.5km horizontal resolution. This assimilation system includes observations from radiosondes, wind profilers, aircraft reports, ship and buoy reports, automated land surface stations (observations of pressure, 2-m temperature and humidity, 10-m wind), infrared radiances from ATOVS, SEVIRI, winds from MSG AMV and scatterometers and GPS ZTD from E-GVAP Network. Furthermore RADAR reflectivity and radial wind observations are also used from French RADAR Network (*Seity et al.,* 2010). This system is soon to be upgraded to **an hourly AROME RUC**. Initialization technique so called Incremental

Analysis Updating (IAU)(*Bloom et al.,* 1995) is able to control imbalances at the beginning of model integration and IAU is also able to compensate the effect of observation loss in forecasts initialized from synoptic short-cutoff hourly updated 3DVAR analyses compared to 3 hourly ones. It means that long AROME forecasts (e.g. started from 12UTC) are incrementally updated by the next short-cutoff analysis as well (i.e. with 13UTC analysis) to improve the skill of AROME long forecasts. Beside hourly AROME 3DVAR RUC assimilation system there is an ongoing activity to build AROME Nowcasting which is basically an hourly non-cycled AROME short-term forecasting system i.e. a production cycle using first guesses of operational AROME RUC. In research **AROME 4DVAR** is under development testing 4D screening and minimisation on 2.5km resolution and employing tangent-linear, adjoint model and simplified physics from ALADIN model into AROME (More details: https://www.wmo.int/pages/prog/arep/wwrp/new/wwosc/documents/auger_arome_da.pdf).

Other existing RUC systems without further details:

- AROME 3h RUC at Austria, Hungary
- ALARO 3h RUC at Slovenia
- HARMONIE 3h RUC at Norwegian, Swedish services
- GRAPES RUC at CMA
- MSM-LFM 3DVAR RUC at JMA

Challenges

One of the major challenges is to <u>control noise accumulation and imbalances</u> for short-range background forecasts. However imbalances and high-frequency components of initial conditions can be removed via initialization techniques, such filtering might be also detrimental concerning mesoscale analysis. From the examples of existing systems there are several operational systems which work 3 hourly analysis update without any initialization procedures (French, Austrian and Hungarian AROME systems and Slovenian ALARO RUC system). On the other hand e.g. at NCEP an hourly RUC system has been run with adiabatic digital filter initialization and IAU is also extensively tested in Meteo-France.

An assimilation scheme using intermittent assimilation cycle assumes that model fields remain stationary within the applied assimilation window. In other words the observation time is assumed to be equal with analysis time for every observations assimilated in an analysis. The length of the assimilation window and this assumption have to be reassessed as the resolution of the data assimilation system is increased. This temporal representativity error can be nicely reduced by RUC approach, however, this advantage implies another challenge regarding the amount of observations used for analyses. For instance such temporal error of AMDAR reports can be reduced comparing an hourly and a 3 hourly updated RUC 3DVAR, but the amount of utilizable AMDAR reports becomes less in an hourly analysis than in the 3 hourly one. Therefore it is an important challenge to <u>ensure observation density</u> and adequate observation constraint for every RUC analysis.

The lateral boundary conditions (LBC) of the background forecasts of RUC assimilation cycle are usually derived from NWP models updated only 4 times (synoptic times) in a day. The coupling is optimal in an intermittent assimilation cycle if the latest available LBCs are used, however, the <u>optimal coupling frequency</u> in an hourly RUC should be studied whether an hourly or subhourly coupling is sufficient or desirable. Additionally to this coupling study it is important to determine the coupling strategy with respect to initialization and the control of noise accumulation i.e. the relevance of space consistent or time consistent coupling at initial time.

To make data assimilation succeed, accurate background error statistics are mandatory. In a 3DVAR RUC data assimilation scheme the forecast error covariances are usually described in a climatological way i.e. background errors are expressed by an average made from a time sequence of forecast differences. Furthermore (in most of the 3DVAR RUC systems) homogenity and isotrophy of these error correlations are also assumed. Such simplifications in a mesoscale data assimilation system is clearly disadvantegeous. To minimize the effects of these simplifications the <u>best estimate of B matrix</u> should be performed using ensemble data assimilation on the resolution of RUC system. On the other hand, more observations we consider, less weight of the background term we will gain with an optimal RUC system which might ease this unfavorable effect of the 3DVAR RUC. On longer term and higher resolution the flow-dependent structure function becomes more and more crucial.

Short-term plans in LACE (*with rough estimates for needed manpower resources*)

First of all two LACE centers are interested to develop an hourly RUC namely ZAMG and OMSZ. Both institutes have an operational 3 hourly updated AROME 3DVAR RUC which might be upgraded to an hourly RUC in the frame of this action. The main goals to be done for establishing an hourly AROME 3DVAR RUC are:

- Investigate the coverage and availability of potentially good observations from OPLACE and other (local) sources. Based on observation monitoring the horizontal and vertical coverage and timeliness of the observations have to be checked. Finally the optimal observation cut-off time has to be determined for RUC analyses.
  (*2 – 3 weeks local work in 2015 to monitor available observations*)
- Perform data assimilation diagnostics (Degree of Freedom for Signal, Moist Total Energy Norm) to check observation influence on analysis and on forecast. Also it helps to verify the observation set used in the RUC system for further developments. Beside only diagnosing observation influence, the accuracy of predefined observation errors can be reassessed e.g. with observation system simulation experiment (OSSE).
  (*2 – 3 months work in 2016 (?) with local work or LACE stay ?*)
- Assess the accuracy of differently sampled background error statistics. Verify the effectiveness of structure functions calculated from 3 hours forecast differences for the hourly RUC system (1 hour forecast ranges). Characterisitics of the background error statistics will be studied by diagnostic tools (e.g. correlation length scales, spectral variance and kinetic energy spectra diagnostics). To improve 3DVAR RUC system, a posteriori diagnostic of observation and background errors (proposed by Desroziers) can be applied to tune proper weights of observations (SIGMAO_COEF) and background forecasts (REDNMC).
  (*1 – 1,5 month work in 2015, roughtly another 3 months in 2016 or after ?*)
- Make spin-up initialization tests using diagnostic tools (Eckevo) to verify existence and seriousness of spurious noises at the beginning of model integration. Also diagnostic tools have to be used to select best initialization method and/or best initial coupling strategy. For initialization Incremental Analysis Update (IAU), (Incremental) Digital Filter (IDFI) and furthermore Scale-Selective DFI (*Termonia,* 2008) will be tested for filtering initial conditions.
  (*1 month LACE stay in 2015 and 1 month local work also in 2015*)
- In first experiments, the LBC coupling frequency will be set to 1 hour. However it is worth considering in latter phase of RUC experiments to try subhourly coupling and verify those case

studies when the lateral boundary conditions could play bigger role even in very short-ranges. (*1 – 2 months local work in 2016 ?*)

Long term plans, opportunities *(2016 and beyond)*

After verifying issues and finding the most crucial problems related to the above mentioned challenges, decisions have to be made which developments are affordable and able to give solutions especially for LACE interest (i.e. for our domain, resolution and forecast purposes).
Regarding applied algorithms the variational data assimilation remains the obvious choice in ALADIN community, however, knowing that the currently used 3DVAR (and also 4DVAR) has major limitations on mesoscale, further methods and/or developments have to be taken into account. Considering also the above mentioned examples, operational or research systems the following developments can further improve or replace basic 3DVAR RUC approach on longer term.

- First of all *Hybrid 3DVAR* is able to bring flow-dependent ascpect of background error estimation and also using so called *grid-point sigmaB maps* which provide sufficient spatial variability is worth considering. Flow-dependency is crucial in mesoscale data assimilation, but LACE needs to collaborate with other centers to get the expertise on it.
- The *nudging method* can bring alternative, fast and effective assimilation algorithm which useful especially to employ RADAR observations. However it has some shortcomings about the formulation of error covariances and retrieval techniques of non-conventional observations. To implement nudging in a LACE DA system, collaboration with other centers is again essential.

Other methods like 4DVAR (or even 4DEnVAR), cloud and/or hydrometeor analysis, multiscale variational method would require significant resources and work from LACE which would be very difficult to fulfill.
Concerning the use of observations on longer term perspective and considering what Fabry and Sun concluded that uncertainties in midlevel moisture caused the greatest and then low-level, midlevel temperature, low-level moisture and midlevel winds contributed in the mesoscale forecast uncertainties special interest should be taken to information on humidity (especially in PBL) and midlevel, low-level winds. For this perspective the following observations and actions would be critical in an hourly RUC:

- Apply accurately RADAR reflectivity and radial wind in data assimilation system. During the first experiements only locally produced and pre-processed RADAR data can be used (e.g. latest results with Hungarian RADAR data had promising impact on AROME forecast), but it is mandatory to cooperate with other centers and being able to use all RADAR information uniformly on longer term. Therefore RADAR data exchange (in LACE and/or through OPERA) remains high priority which has to be continued in the future.
- Screen level observations are going to be important component of the systen for describing the low-level environment of the PBL like convergence.
- Use more observations from Meteosat satellite (e.g. SEVIRI WV channels and HRW AMV)
- Investigate further GNSS products like ZTD, Slant delay and refractivity
- Apply Mode-S observations (EHS and MRAR as well)

References

1. *Benjamin, S. G., and Coauthors, 2004: An hourly assimilation-forecast cycle: The RUC. Mon. Wea. Rev., 132, 495-518.*
2. *Brousseau, P., Berre, L., Bouttier, F., Desroziers, G., 2011: Background-error covariances for a convective-scale data-assimilation system: AROME–France 3D-Var, Quart. J. Roy. Meteor. Soc., 137, 409-422.*
3. *Seity, Y., Brousseau, P., Malardel, S., Hello, G., Bénard, P., Bouttier, F. Lac, C., Masson, V., 2010: The AROME-France Convective-Scale Operational Model, Mon. Wea. Rev. 139, 976-991.*
4. *Fabry, F., and Sun, J., 2009: For How Long Should What Data Be Assimilated for the Mesoscale Forecasting of Convection and Why? Part I. Mon. Wea.Rev. 138, 244 – 255*
5. *Termonia, P., 2008: Scale-Selective Digital Filtering Initialization. Mon. Wea. Rev. 136. 5246 – 5255*
6. *Huang, X.-Y., and P. Lynch, 1993: Diabatic digital filter initialization: Application to the HIRLAM model. Monthly Weather Review, **121**, 589-603.*
7. *Presentation: Rapid Refresh operational upgrade to version 2 at NCEP, 2014 February 18-19, RAPv2 webinar briefings to NWS FOs, Regions (http://ruc.noaa.gov/pdf/RAPv2-NWSwebinar-18feb2014-FINAL.pdf)*
8. *Korsholm, U. S., Sass. B. H., Nielsen N. W., and others, 2014: A new approach for assimilation of 2D radar precipitation in a high-resolution NWP model. Meteorological Applications (2014)*
9. *Xie, Y., S. Koch, J. McGinley, S. Albers, P. E. Bieringer, M. Wolfson, and M. Chan, 2011: A space–time multiscale analysis system: A sequential variational analysis approach. Mon. Wea. Rev., 139, 1224–1240.*
10. *C. D. Jones and B. Macpherson, 1997: A latent-heat nudging scheme for the assimilation of precipitation data into an operational mesoscale model. Meteorol. Appl. 4, 269-277*
11. *Zoltan Toth, Mark Tew, Daniel Birkenheuer, Steve Albers, Yuanfu Xie, and Brian Motta, 2014: Multiscale Data Assimilation and Forecasting. Bull. Amer. Meteor. Soc., **95**, ES30–ES33.*
12. *S. C. Bloom, L. L. Takacs, A. M. da Silva, and D. Ledvina, 1996: Data Assimilation Using Incremental Analysis Updates. Mon. Wea. Rev., **124**, 1256–1271.*