Dual Scale Neighboring Ensemble Approach for the Cloud-Resolving Model Ensemble Variational Assimilation

Kazumasa Aonashi\textsuperscript{a}, Kozo Okamotob, Munehiko Yamaguchia and Seiji Origuchic

\textsuperscript{a} Typhoon Research Department, Meteorological Research Institute, Japan, aonashi@mri-jma.go.jp, \textsuperscript{b} Meteorological Satellite and Observation System Research Department, Meteorological Research Institute, Japan, \textsuperscript{c} Forecast Research Department, Meteorological Research Institute, Japan.

The purpose of the present study is to develop a sampling error damping method for the Cloud-Resolving Model (CRM) Ensemble-based Variational Assimilation (EnVA). This is because, in ensemble-based assimilation schemes for CRMs, sampling error is serious, in particular, for precipitation-related variables (precipitation rate, vertical wind speed) because they are confined in rainy areas [1].

Based on the CRM ensemble forecast error analyses for various precipitation cases, we adopted a Neighboring Ensemble (NE) method and a dual scale separation of NE as the sampling error damping method. The NE method approximated the forecast error correlation using NE members within a reduced-grid box (5 x 5 grids in the present study) based on the spectral localization assumption [2]. In the dual scale separation, we divided the NE forecast error into large-scale portions (13 x 13 grid averages in the present study) and small-scale deviations so as to reflect the horizontal scale differences in forecast error between precipitation-related variables and others.

In order to introduce the sampling error damping method to the CRM EnVA, we assumed that the EnVA analysis increments were subject to the dual scale NE forecast error subspace. In addition, we reduced the vertical dimension of the subspace by approximating the subspace with the primary Singular Value Decomposition (SVD) modes of the vertical cross correlation of the dual scale NE forecast error.

The EnVA scheme of the present study derived the optimal analysis increments by minimizing the three-dimensional cost function in the subspace spanned by the vertical SVD primary modes. Since the SVD modes were mutually independent, the cost function resulted in that for the horizontal component of the analysis increment of the each SVD mode. Then, we horizontally diagonalized the background term of the cost function using the horizontal correlation of the NE forecast error. We used the conjugate gradient scheme to solve the nonlinear minimization of the cost function, and obtained the optimal analysis increment of the ensemble mean [1]. Then we calculated the analysis of the each ensemble member using Zupanski’s method [3].

References
Retrospective Convective-Scale Data-Assimilation Experiments for Warn on Forecast

David Dowell\textsuperscript{a}, Ming Hu\textsuperscript{b}, Curtis Alexander\textsuperscript{b}, Stan Benjamin\textsuperscript{a}, Steve Weygandt\textsuperscript{a}, Lou Wicker\textsuperscript{c}, Dusty Wheatley\textsuperscript{d}, Corey Potvin\textsuperscript{d}, and Thomas Jones\textsuperscript{d}

\textsuperscript{a} NOAA/Earth Systems Research Laboratory, Boulder, Colorado, USA, David.Dowell@noaa.gov
\textsuperscript{b} Cooperative Institute for Research in Environmental Sciences, Boulder, Colorado, USA
\textsuperscript{c} NOAA/National Severe Storms Laboratory, Norman, Oklahoma, USA
\textsuperscript{d} Cooperative Institute for Mesoscale Meteorological Studies, Norman, Oklahoma, USA

NOAA’s Warn-on-Forecast project is developing numerical weather prediction (NWP) techniques for very-short-range (0-1 h) prediction of severe weather: tornadoes, other strong winds, hail, and heavy rain. Such NWP systems require model grid spacing of 1 km or less, radar and satellite data assimilation (DA) at convective scales, ensemble forecasting, and frequent updates (~5 min) of analyses and forecasts.

To help us achieve the goal of improving high-resolution, rapidly-updated NWP for severe weather forecasting and warning, we are developing a testbed for DA and NWP techniques for retrospective periods with significant severe weather. This retrospective testbed will allow us to explore a parameter space including radar and satellite DA techniques [including ensemble Kalman filter (EnKF) and 3D Variational (3DVar) methods], multi-scale data assimilation, model resolution, etc. As a starting point, we are producing background ensemble analyses and forecasts like those proposed for future operational NOAA ensemble NWP systems: a 13-km North American Rapid Refresh Ensemble (NARRE) and a 3-km High Resolution Rapid Refresh Ensemble (HRRRE). Then, for the Warn-on-Forecast applications, we will nest smaller, higher-resolution grids into these ensembles. Our initial retrospective period includes destructive storms (e.g., the 24 May 2011 Oklahoma tornado outbreak and the 22 May 2011 Joplin, Missouri tornado) with significant forecast and warning challenges.

At the workshop, we will report on results to date for the retrospective experiments. In particular, we will discuss the sensitivity of the high-resolution ensemble forecasts to assimilated data (radar and/or satellite) and assimilation technique (e.g., EnKF or 3DVar), providing the opportunity to evaluate tradeoffs of computational requirements and forecast skill.
The Local NWP system is a high-resolution regional weather forecast and data assimilation system, aimed at providing information for aviation operation and disaster prevention. The system is in operation at the Japan Meteorological Agency (JMA) starting from August 2012. In the Local NWP system, the Local Analysis (LA; [1]) produces the initial condition of the 9-hour forecast of the Local Forecast Model (LFM; [1]), a convection-permitting model with a horizontal grid spacing of 2km.

Compared to the Meso-scale Model (MSM; [1]), another operational limited-area model with a lower horizontal resolution of 5km, the LFM puts more emphasis on predicting localized and short-lived severe events. The Local NWP system is thus designed to be suitable for providing rapid forecast guidance and frequent updates of the high resolution very short-range forecast reflecting information from the latest possible observations. Although the current operation runs the LFM every 3 hours on a limited domain covering the eastern part of Japan, the operation is planned to be enhanced in 2013 to become more clearly based on this design, providing hourly updates of the LFM forecast on an extended domain covering whole of Japan and its surrounding area.

In the JMA operation, the LA is scheduled to start at 30 minutes past the hour, and all the LA and the LFM processes are required to complete in 30 minutes, realizing the design of rapid and frequent updates of the forecast. In order to keep this strict schedule, the LA uses a 3D-Var data assimilation scheme, instead of applying 4D-Var, a more advanced but computationally more demanding scheme used to initiate the MSM. In the LA analysis cycle, hourly 3D-Var data assimilations and 1-hour forecasts are iterated in turn for 3 hours at a horizontal resolution of 5km. The analysis cycle uses the latest MSM forecast as the first guess, and assimilates observations received over the latest 4 hours in each operation.

Remote sensing observations including those from weather Doppler radars and ground-based GNSS are assimilated in the LA as important sources of detailed information that can contribute to a better forecast of high impact phenomena. Radar reflectivity data (assimilated as RH pseudo observations) have recently been introduced to show overall improvement in precipitation forecast of the LFM. Taking into account capability of high-resolution NWP to capture small-scale variations of the atmospheric state near the surface, the LA also assimilates surface temperature, wind, and humidity observations from automated weather stations ahead of other JMA operational data assimilation systems in lower resolutions, in order to appropriately reflect effects from local-scale environments near the surface.

The presentation will show details of this LA system characterized as a data assimilation system for a high-resolution and high-frequency NWP, including various developments to improve this system.

References
Improving Forecasts of Tropical Cyclone Intensity by Using an Ensemble Kalman Filter to Estimate Unknown Model Parameters

Benjamin W. Green and Fuqing Zhang

Department of Meteorology, The Pennsylvania State University, University Park, PA, United States, Email: bwg5019@psu.edu

Although data assimilation has made significant progress in estimating the (initial) atmospheric state, forecast skill will continue to be limited by imperfect forward models – i.e., model error. One emerging approach to reduce model error is to apply data assimilation techniques such as the ensemble Kalman filter (EnKF) not just to state variables but also to “model parameters,” which are unknown/uncertain constants in the forward model. This method, hereafter referred to as “Simultaneous State and Parameter Estimation” (SSPE), has already been demonstrated to improve forecasts of the planetary boundary layer in a full-physics model [1]. Furthermore, successful implementation of SSPE requires that the chosen model parameters have a distinguishable, straightforward, and noticeable impact on the state variables [2].

The present research is building towards implementing SSPE in a convection-permitting full-physics mesoscale model used for tropical cyclone (TC) forecasting. Here, the parameters of interest are associated with the exchange coefficients for fluxes across the air-sea interface of momentum \((C_D)\) and moist enthalpy \((C_k)\); these coefficients have long been known to strongly influence TC intensity. Sensitivity tests [3] were in general agreement with such prior work, and also showed that \(C_D\) affects the relationship between the two common metrics of TC intensity (maximum 10-m wind speed and minimum central pressure). More rigorous sensitivity tests have identified a parameter that controls the magnitude of \(C_D\) for all wind speeds as most suitable for estimation. The SSPE experiments are presently underway and the results will be presented at this symposium. Even without SSPE, the parameter sensitivity experiments have identified ways to improve numerical forecasts of TC intensity, which is crucial to reducing the losses to life and property.

References


Multi-Scale Ensemble Kalman Filter Data Assimilation and Forecasts of the 10 May 2010 Tornado Outbreak in Central United States

Youngsun Jung\textsuperscript{a}, Ming Xue\textsuperscript{ab}, Yunheng Wang\textsuperscript{a}, Yujie Pan\textsuperscript{a}, and Kefeng Zhu\textsuperscript{a}

\textsuperscript{a}Center for Analysis and Prediction of Storms (CAPS), University of Oklahoma (OU), USA, youngsun.jung@ou.edu, \textsuperscript{b}School of Meteorology, University of Oklahoma, USA.

The parallel ensemble square-root Kalman filter (EnSRF) algorithm [1] developed recently at the Center for Analysis and Prediction of Storms (CAPS) for assimilating multi-scale observations is applied to the May 10, 2010, Oklahoma-Kansas tornado outbreak that spawned more than 60 tornadoes with up to EF4 intensities [2]. To properly initialize both synoptic and meso-scale environment and the convective scale features, a nesting strategy is used, with the storm-scale analyses at 4-km horizontal grid spacing nested inside the continuously cycled regional analyses at a 40-km grid spacing. The former includes all observations used by the operational Rapid Refresh system.

The 4-km storm-scale domain covers a 1760 × 1920 km\textsuperscript{2} region, uses the Advanced Regional Prediction System (ARPS) as the prediction model. Conventional (sounding, profiler, surface station and mesonet) observations and data from more than 40 WSR-88D radars are assimilated every hour, while during the last hour before the free forecasts the data are assimilated every 10 minutes. Ensemble and deterministic forecasts are launched several times during the assimilation cycles.

The results showed that the parallel EnSRF algorithm exhibits good scalability for very dense radar observations. The analyzed reflectivity fields at the end of each assimilation window exhibits a good fit with the observations in shape, structure, and intensity. The ensuing deterministic and ensemble forecasts captured well the line of strong, isolated storms with supercell characteristics in the central Kansas and Oklahoma.

Based on the testing results, CAPS will run the above EnKF system interfaced with the Weather Research and Forecasting (WRF) model at 4 km grid spacing, in real-time during the spring of 2013 as part of the NOAA Hazardous Weather Testbed Spring Experiment (http://forecast.caps.ou.edu/) over a ¼ continental U.S. domain. Some of the results will also be reported at the symposium.

References
The objective of the study is to simulate the special features of the pre-monsoon Bay of Bengal cyclone Aila (23-26 May 2009) after landfall. Weather Research & Forecasting (WRF) model with 3 nested domains (60km, 20km and 6.6km) and two-way interaction, is used. The initial and boundary conditions are supplied from FNL dataset with RTG-SST. The single combination of physical parameterization schemes i.e. BMJ as cumulus, WSM as microphysics, YSU as Planetary Boundary Layer (WSM-YSU-BMJ) is considered. The special feature of Aila is its northward movement throughout its life period and its rapid intensification just after the landfall. It maintained its cyclone intensity up to 15 hours after landfall. The results from the model are examined at every 6hr interval and 1hr interval.

Northward movement throughout its life period and the intensification after the landfall are very well captured in the numerical experiment. The model predicted landfall is 3-4 hrs late than the observed landfall and the landfall error is found to be 83 km. Model simulated cyclone maintained its intensity for 12hrs after model landfall. The detail features could be understood clearly when the computed results are examined at every 1hr interval. Thus the observed special features of the cyclone Aila are well captured by the WRF model though the intensity is over predicted. The vertical structure of Aila is also compared with the observed vertical structure before and after the landfall. The role of Four Dimensional Data Assimilation (FDDA-nudging) is also discussed in detail.
Self-Breeding: A new Approach to the Estimation of Uncertainty Structures in Meso-Scale NWP models

Jan D Keller\textsuperscript{a,b}, Liselotte Bach\textsuperscript{a,c}, and Andreas Hense\textsuperscript{c}

\textsuperscript{a} Climate Monitoring Branch, Hans-Ertel-Center for Weather Forecasting, Germany, jkeller@uni-bonn.de, \textsuperscript{b} Deutscher Wetterdienst, Germany, \textsuperscript{c} Meteorological Institute, University of Bonn, Germany.

The estimation of fast growing error modes of a system is a key interest of ensemble data assimilation when assessing uncertainty in initial conditions. Over the last two decades three methods (and variations of these methods) have evolved for global numerical weather prediction models: ensemble Kalman filter, singular vectors and breeding of growing modes (or now ensemble transform). While the former incorporates a-priori model error information and observation error estimates to determine ensemble initial conditions, the latter two techniques directly address the error structures associated with Lyapunov vectors. However, in global models these structures are mainly connected to global wave patterns.

When using meso-scale limited area models, these perturbations structures are therefore often included using perturbed boundary conditions while the initial perturbations (when used) are often generated with a variant of an ensemble Kalman filter which does not necessarily focus on the fast-growing error structures.

In the framework of the European regional reanalysis project of the Hans-Ertel-Center for Weather Research we use a meso-scale model with an implemented nudging data assimilation scheme which does not support ensemble data assimilation. In preparation of an ensemble-based regional reanalysis and for the estimation of three-dimensional atmospheric covariance structures, we implemented a new method for the assessment of fast growing error modes for meso-scale limited area models: The so-called self-breeding is an adaption of the breeding of growing modes technique which can be used to identify uncertainty structures arising from short time scale phenomena such as convection.

In the self-breeding system, initial perturbations are integrated forward for a short time period and then rescaled and added to the initial state again. Iterating this rapid breeding cycle provides estimates for the initial uncertainty structure (or local Lyapunov vectors) given a specific norm for an arbitrary time step (not necessary an analysis time step). We present results from case study experiments, which show the ability of the self-breeding cycle to produce reasonable uncertainty structures for convective events.
On the Benefits of a High-Resolution Analysis for Convective Data Assimilation of Radar Observations using a Local Ensemble Kalman Filter

Heiner Lange and George C. Craig

Hans Ertel Centre for Weather Research Department, Data Assimilation Branch, LMU Munich, Germany, heiner.lange@physik.lmu.de

The DWD is developing an implementation of the Local Ensemble Transform Kalman Filter (LETKF) [1] for the cloud resolving COSMO model. This study shows in an idealized convective testbed that the LETKF is able to perform storm-scale Data Assimilation of simulated Doppler radar observations. Localizing the observation error covariances, the analysis quality of convective storms appears comparable to assimilation systems that use algorithms like the EnSRF that localize the background error covariances [2,3].

It is investigated in perfect model experiments how the limited predictability of convective storms affects precipitation forecasts by comparing a fine scheme with low analysis error to a coarse scheme that allows variance regarding position, shape and occurrence of storms in the ensemble. To get there, the coarse scheme uses averaged superobservations and a coarser evaluation of the analysis weights, a larger localization radius and a weaker Gaussian constraint on the analysis solution.

Performing 3-hour forecasts of convective systems with typical lifetimes exceeding 6 hours, forecasts from the detailed analyses of the fine scheme are found to be advantageous to those of the coarse scheme during the first 1-2 hours, regarding the predicted storm positions. After 3 hours in the convective regime used here, the forecast quality of the different schemes appears indiscernible, judging by RMSE and verification methods for rain-fields and objects.

It is concluded that, for operational assimilation systems, the analysis might not necessarily need to be detailed on the grid scale of the model. Depending on the forecast lead time, and on the presence of orographic or synoptic forcings that enhance the predictability of storm occurrences, analyses from a coarser scheme might suffice. As a positive side-effect, the computational cost of the Kalman Filter solution can be reduced strongly.

References
Spatial Filtering of Small Ensemble-Based Estimations of Background Error Parameters at Convective Scale.

Benjamin Ménétrier\textsuperscript{a}, Thibaut Montmerle\textsuperscript{a}, Loïk Berre\textsuperscript{a} and Yann Michel\textsuperscript{a}

\textsuperscript{a}CNRM/GAME, France, benjamin.menetrier@meteo.fr

Background error covariance modeling and estimation is a key point of variational data assimilation systems used in main meteorological centers. Current covariances are often stationary and uniform across the domain, whereas it is well established that they should be heterogeneous and flow-dependent. A current challenge is thus to add flow-dependency in background error covariance models.

Our strategy is to run a small ensemble (6 members) of perturbed forecasts that simulate background errors, from which we can draw flow-dependent statistics. However, noise due to sub-sampling must be filtered out before any use in the spatial transform of our covariance model. Objective spectral filters \cite{Raynaud2009} have been successfully implemented for global models, but new issues arise for limited-area models at convective scale, such as the operational AROME-France model. Spatial filters, that ensure the positiveness of filtered variances and that handle field non-periodicity at the borders, have been especially developed and evaluated against reliable variances deduced from a large ensemble (90 members) for an intense convective event. Such homogeneous filters, based on statistics of the raw and filtered variances, give similar results than other methods based on heterogeneous filtering, but with a much lower computational cost.

Another interesting parameter of background error is the Hessian tensor of the local correlation function (LCH tensor, \cite{Weaver2012}). This tensor provides a diagnostic information about heterogeneity and anisotropy of correlation functions at their origin, and can also be used as an input of correlation models using a diffusion equation \cite{Weaver2012}. Even more than for variances, LCH tensors estimated with small ensembles suffer from sub-sampling noise, that have to be damped before any further use. A nice feature of filters developed formerly for variances is their straightforward application to tensor components filtering. Moreover, assuming that all components are filtered in the same way, the positiveness of the filter ensures the positive-definiteness of filtered tensors, which is required.

Thus, robust and useful estimations of background error variances and LCH tensors can be obtained from a small ensemble after a positive, adaptive and cheap filtering step.

References


Estimating deformations of random processes for correlation modelling in data assimilation

Y. Michel\textsuperscript{a}, R. Legrand\textsuperscript{a}, J. Beezley\textsuperscript{a,b}

\textsuperscript{a} CNRM-GAME, Météo-France and CNRS, Toulouse, France.
\textsuperscript{b} CERFACS, Toulouse, France.

Data assimilation makes extensive use of covariance models in order to describe the statistical structure of errors that are present in the observations, in short term forecasts, and in the numerical model. Building on work in the computer vision community, we introduce \[2,3\] the `shape from texture' approach \[1\] for the modelling of covariances and correlations in data assimilation with large dimensions. In this framework, the covariance model is obtained as the deformation, or coordinate transform, of a stationary covariance model. Contrary to some coordinate transforms already proposed in the literature, here the deformation is objectively estimated from the data.

The energy of the deformed process is measured at different scales and orientations by a continuous wavelet analysis. The scalogram is shown to obey a `Texture Gradient Equation' that relates its derivatives to local metric changes. The deformation gradient can be estimated from a single realization of the deformed process, and integrated to recover the deformation. Estimating the inverse of the deformation allows to spatially stationarize the process. These steps define linear interpolating operators for the direct, adjoint and approximate inverse deformation, which can be used in the control variable transform in variational data assimilation schemes.

We also highlight that the representation of spatially deformed background error covariances is in agreement with the propagation equation of the Kalman filter when advection is a leading process in the numerical model, and when the analysis error covariance matrix is more homogeneous and isotropic than the background error covariance matrix which is the case when the observing network is dense. We show that this modelling of the correlations has interesting properties such as it does not require accurate re-normalization of the variances, it allows geographical variability of the correlations and it is computationally feasible. The algorithm is applied to the modelling of background error covariances in the convective scale model AROME from Météo-France, and is compared qualitatively to other approaches such as the recursive filters and the diagonal assumption in a wavelet basis.

References


Correlated Observation Errors in High Resolution Data Assimilation

N.K. Nichols\textsuperscript{a}, J.A. Waller\textsuperscript{a}, S.L. Dance\textsuperscript{a}, A.S. Lawless\textsuperscript{a}, L.M. Stewart\textsuperscript{b}, J.R. Eyre\textsuperscript{b}

\textsuperscript{a}School of Mathematical and Physical Sciences, University of Reading, UK, \texttt{n.k.nichols@reading.ac.uk}.

\textsuperscript{b}Remote Sensing, Met Office, UK

Remote sensing observations often have correlated errors, but the correlations are generally not taken into account in data assimilation for numerical weather prediction (NWP). Correlated errors of representativity are present between channels that observe spatial scales or features that the model does not represent well. Errors in the forward model, such as those of spectroscopy, may also be correlated between channels. The assumption of zero correlations is often used with data thinning and inflation methods, resulting in a loss of information [1]. Recently it has been demonstrated that using approximate observation correlations in data assimilation can give more accurate analyses than using inflation techniques and can be implemented practically [2]. As operational centres move towards higher-resolution forecasting, there is a requirement to make better use of available observations in order to retain data providing detail on many scales.

In previous work, error correlations in satellite observations from certain instruments have been identified that may be caused by representativity error [3]. Errors of representativity are the result of small scale observational information being incorrectly represented in the model. In this work we aim to achieve a better understanding of these errors to allow them to be incorporated into the observation error statistics in data assimilation. Initially a technique for diagnosing static representativity error covariances has been implemented in which it is assumed that the observations can be written as the mapping of a high resolution state into observation space and that the model state is a truncation of the high resolution state [4]. We have applied this technique to determine the structure of static representativity errors in a nonlinear advection-diffusion model with multi-scale behaviour and have also applied the method to temperature and humidity data from the Met Office UKV system [5]. The results from these experiments show that errors of representativity are correlated and are state and time dependent. We show also that these errors vary with height throughout the atmosphere and are more significant for humidity than temperature. It is demonstrated that these errors are reduced where the resolution of the model is increased or where the observation length-scale is increased, but that the variance is independent of the number of observations available.

From this work we have concluded that although this diagnostic method can be used to reveal the structure of representativity errors, the results are not readily applicable in data assimilation due to the underlying assumptions. We have now developed and tested a new method for diagnosing and incorporating time-dependent representativity error covariances in an ensemble data assimilation system. The new work is the subject of another joint abstract submitted to this symposium by J.A. Waller.

On the Use of Data Assimilation Methodologies for Examining Cloud System - Environment Interactions

Derek J. Posselt

Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan, USA, dposselt@umich.edu

While data assimilation (DA) has many applications, its fundamental purpose is the combination of information from disparate sources [1,2]. In most modern DA algorithms, each piece of information is associated with a probability distribution. These are then related through a model that maps from one probability space into another. The outcome is an estimate of the probability structure of one or more variables of interest conditioned on each piece of information; typically prior knowledge, a set of observations, and the formulation of the model itself. Information derived from this probability distribution may include an optimal estimate and/or measures of variability and relationship between variables (e.g., (co)variance).

This presentation demonstrates how this very general perspective on data assimilation can be used to explore the fundamental relationships in a physical system. Specifically, a Markov chain Monte Carlo inverse algorithm [3,4] is used to compute the probability distribution of cloud variables in a deep convective cloud system, joint with the system dynamics, radiative fluxes and heating rates, and thermodynamic environment. The results clearly depict the multivariate functional relationships between cloud microphysics and the system state. It is also clear that, when cloud microphysical characteristics are constrained with observations, many aspects of the deep convective structure are also uniquely determined. Where this is not the case, the results provide guidance as to which observations are required to produce robust estimates of convective dynamics and environment, as well as their uncertainty characteristics.

References


Local Ensemble Transform Kalman Filter (LETKF) for the convection-permitting NWP model COSMO-DE

Hendrik Reich\textsuperscript{a}, Andreas Rhodin\textsuperscript{a}, Christoph Schraff\textsuperscript{a}, Yuefei Zeng\textsuperscript{a}, Ulrich Blahak\textsuperscript{a}

\textsuperscript{a}Research and Development section, German weather service (DWD), Germany, hendrik.reich@dwd.de

We report on recent experiments with the Local Ensemble Transform Kalman Filter (LETKF) [1], which is being developed and tested for the operational regional model COSMO-DE of DWD (German weather service) and its ensemble version COSMO-DE-EPS. We describe the setup of the COSMO-LETKF, including the use of ensemble lateral boundary conditions. These are produced by the global model GME, which is also driven by a LETKF.

The use of high-density data such as radar radial winds [2] and the consequences for the choice of the localization radius are discussed. One possible approach is to use different observation types in several successive analysis steps (multi-step analysis). We also report on our experience with (adaptive) methods to increase the ensemble spread and to estimate the observation error [3,4].

References
Impact and Verification of Microphysical Parameterizations on Supercell Thunderstorm Cold Pools using WRF/DART EnKF Data Assimilation Experiments

Anthony E. Reinhart\textsuperscript{a}, Christopher C. Weiss\textsuperscript{a}, and David C. Dowell\textsuperscript{b}

\textsuperscript{a} Department of Geosciences, Atmospheric Science Group, Texas Tech University, USA, anthony.reinhart@ttu.edu, \textsuperscript{b} NOAA/ESRL, USA.

An ongoing study is considering the ability of numerical weather prediction microphysical parameterizations to properly simulate supercell cold pools. Inaccuracies in these parameterizations have led typically to an overestimation of high-level clouds, precipitation amounts, and magnitude of evaporative cooling, which impact the evolution and strength of the supercell cold pool. Real data simulations using WRF/DART and assimilating WSR-88D and mobile radar radial velocity data onto a 1 km domain every two minutes were conducted. The EnKF technique was used in order to minimize the initial condition error and otherwise best produce the observed atmospheric state, allowing for a focus on errors attributed to bulk microphysical parameterizations.

This study investigates two cases from the Verification of the Origins of Rotation in Tornadoes Experiment 2 (VORTEX2) using two different microphysical parameterizations (Milbrandt-Yau and Morrison) to determine which of these sophisticated two moment bulk parameterizations produce the most realistic cold pools. Using in-situ observations collected during these cases it is possible to verify the supercell cold pool at a high temporal and spatial scale, allowing for detailed investigation as to why one parameterization is producing a better cold pool in a portion of the supercell. Droplet breakup and fall speed of particles seems to be a major contributor to the differences in the cold pools from the simulations. Presented will be the verification results of both cases and physical explanation as to why the Morrison parameterization is performing better in the forward flank compared to the Milbrandt-Yau parameterization. In addition, preliminary investigation and results into a multiparameter EnKF ensemble will be discussed.
Improving Convective Forecast Skill via Ensemble Data Assimilation with WRF-DART

Glen Romine\textsuperscript{a}, Ryan Torn\textsuperscript{b}, Morris Weisman\textsuperscript{c}, Craig Schwartz\textsuperscript{c}, and Jeff Anderson\textsuperscript{c}

\textsuperscript{a}National Center for Atmospheric Research, Boulder, CO USA, romine@ucar.edu, \textsuperscript{b}Department of Atmospheric and Environmental Sciences, University of Albany, Albany, NY USA, \textsuperscript{c}National Center for Atmospheric Research, Boulder, CO USA.

Convective forecasts remain a considerable challenge \cite{1, 2} and probabilistic forecasts provide a path toward better quantifying convective forecast uncertainty. Ensemble data assimilation systems can provide initial conditions to probabilistic forecasts. Where residual variance remains in the analysis, assimilation of supplemental observations in these regions can further reduce initial condition uncertainty and may lead to improvements in probabilistic forecast skill. During Spring 2013, the Mesoscale Predictability Experiment (MPEX) seeks to improve short-term (here 6-15 h) forecasts of convective weather episodes over the Great Plains. This will be achieved by increasing observation density in the vicinity of small-scale disturbances upstream of anticipated convective weather events where initial conditions are anticipated to be less certain and the assimilation of additional data could impact the subsequent forecast of convection. In addition, supplemental radiosondes will be released in the vicinity of the target region during the time convection is expected to develop. Realtime forecasts will be initialized from a continuously cycled WRF-DART ensemble data assimilation system, similar to past seasons \cite{3} except in 2013 a 10- or 30-member 48 h convection permitting ensemble forecast will be made twice daily. Ensemble sensitivity analysis (ESA) \cite{4} will offer guidance for realtime operations by identifying potential target regions for dropsondes and supplemental radiosondes.

In retrospective experiments the impact of the additional mesoscale spaced (~150 km) dropsonde data will be assessed through a set of data denial experiments (with and without supplemental dropsonde data). Verification of ensemble forecasts will be made against conventional observations, supplemental radiosondes, and Stage IV precipitation analysis. Moreover, we will also assess the relative utility of the ESA to identify a priori targeted observation locations for convection forecasts. At the workshop, we will provide a brief overview of MPEX, assess general performance characteristics the realtime WRF-DART analysis and forecast system, and preliminary results from retrospective case studies.

References


Assimilation of Cloud Information at the Convective Scale with the Ensemble Kalman Filter

Annika Schomburg\textsuperscript{a}, Christoph Schraff\textsuperscript{b}

\textsuperscript{a}Deutscher Wetterdienst, Germany, annika.schomburg@dwd.de

Convective scale data assimilation is an area of active research. Ensemble Kalman filters have several properties which are advantageous for this purpose. They are comparatively easy to implement and parallelize, no adjoint or linearized models are needed. In principle any quantity can be assimilated, also variables which are not state variables of the model, as in the analysis step the analysis ensemble is obtained by weighting the background perturbations such that they fit the observations in an optimal sense.

We will present an approach to assimilate cloud information into a convection-permitting numerical weather prediction model with the ensemble Kalman filter. The cloud observations are obtained from satellite cloud products based on Meteosat SEVIRI data. To assure data quality and for obtaining an observation error estimate, the satellite cloud products are merged with radiosonde-derived cloud top information where available. Cloud top height and relative humidity at the cloud top height are assimilated for cloudy pixels; the information zero cloud cover is assimilated for low, medium and high clouds for cloud-free pixels, respectively. Thus, both, “cloud” as well as “no cloud” observations are assimilated. An objective is to improve the simulation of low stratus clouds in synoptically stable high pressure systems in fall and winter.

Single observation experiments have been carried out to investigate the effect of the data on the analysis in detail. More sophisticated experiments are under way to find an optimal setting with respect to data density, localization etc.
Data Assimilation for Flows which Possess Many Scales of Motion

Chris Snyder

NCAR, Boulder, Colorado, USA.

As available computing increases, data-assimilation systems have begun to resolve multiple scales of motion. Lorenz (1969) demonstrated in a model of isotropic, homogeneous turbulence how the predictability of flows with a range of scales could change qualitatively depending on whether the exponent of their kinetic-energy power law was greater than, or less than or equal to, -3. Idealized data assimilation in the same model reflects this underlying behavior. When the kinetic-energy exponent is equal to -3 [the situation that characterizes atmospheric motions for scales larger than O(100 km)], cycling data assimilation generically captures scales smaller than those resolved by the observational network. In the opposite case, with an exponent larger than -3 and thus a flatter kinetic-energy spectrum, recovery of unobserved scales by the assimilation scheme is much more limited. In addition, the magnitude of the effects of forecast-model error, when that error is sufficiently small, depend sensitively on both their spectral shape, i.e. whether the model error affects primarily large or small scales, and the kinetic-energy power law of the flow. All these properties follow from the fact that the power law of the flow determines whether differences between two realizations of the flow grow most rapidly at large scales or small.

References

Observation Impact in a Convective-Scale Localized Ensemble Transform Kalman Filter

Matthias Sommer\(^a\), Martin Weissmann\(^b\), and Andreas Rhodin\(^c\)

\(^a\)Hans Ertel Centre for Weather Research Department, Data Assimilation Branch, LMU Munich, Germany, matthias.sommer@lmu.de. \(^b\)Hans Ertel Centre for Weather Research, Data Assimilation Branch, LMU Munich, Germany. \(^c\)Deutscher Wetterdienst, Offenbach, Germany.

In operational weather forecasting, knowledge about the impact of different observations is crucial to refine the observing and data assimilation system. However, assessing this quantity by direct computation (data denial experiments) is usually not feasible because of its high computational cost. This has motivated the derivation of approximated forms of observation impact. If an adjoint model is available, established methods exist that give a reliable estimate of this quantity. In an ensemble-based environment, such an algorithm has been suggested only recently \([1, 2]\). It uses the ensemble analysis and forecast deviations to approximate forecast error difference and consequently also observation impact of runs initialized with different observations. This has now been implemented for the future limited-area ensemble system of Deutscher Wetterdienst (DWD) and has been thoroughly verified with data-denial experiments. The peculiarities for an application on this scale include a strongly non-linear behavior and a typically small localization length. While the former can be expected to be skillfully treated by the ensemble algorithm, the latter imposes constraints for a reasonable choice of lead time. It could be shown that valuable information, such as the detection of disadvantageous observations can be extracted. This talk shows the feasibility and distinctive features of the method for a convective-scale setup, presents examples from a pre-operational application at Deutscher Wetterdienst, and discusses the sensitivity to lead time, localization and verification norm.

References


Convective Scale Data Assimilation at the Australian Bureau of Meteorology

Peter Steinle, Susan Rennie, Xingbao Wang, Yi Xiao, Justin Peter, Alan Seed, Mark Curtis

Centre for Australian Weather and Climate Research – A Partnership between the Bureau of Meteorology and CSIRO, Australia. p.steinle@bom.gov.au

Over the past 3 years, the Australian Bureau of Meteorology has been assessing the potential of a convective scale numerical weather prediction (NWP) system capable of assimilating radar data – both Doppler radial winds and precipitation data. The aim is for the new NWP system to bridge the gap between purely observation based precipitation nowcasting and existing regional scale NWP systems. The system is being developed as part of the broader modeling effort of the Australian Community Climate and Earth System Simulator (ACCESS, [1]). The NWP component of this model is in turn based on the UK Met Office Unified Model and variational assimilation system – specifically the 1.5km UKV system [2].

An important part of this system is the ability to provide a rapid update to forecasts by using a short (hourly or 3-hourly) assimilation cycle. Extensive trials have been carried out from September 2011 to July 2012, as well as for specific periods over 2010-11. Despite the differences in observation networks and weather conditions between Australian and the UK the system is providing guidance far superior to existing global and regional NWP systems. This presentation will discuss some of the challenges in applying this system to tropical or semi-tropical conditions as well as an overview of the performance of the 1.5km system relative to other systems. These issues cover many aspects of data assimilation: from quality control, error covariances, dealing with large scale errors from the host model and the limitations posed by model errors, particularly as they impact on short term prediction of intense rainfall events.

References


Comparison of Two Pairs of Momentum Control Variables in WRFDA for Convective-scale Data Assimilation

Juanzhne Sun\textsuperscript{a}, Hongli Wang\textsuperscript{a}, Wenxue Tong\textsuperscript{b}, Xiangyu Huang\textsuperscript{a}, and Dongmei Xu\textsuperscript{b}

\textsuperscript{a}National Center for Atmospheric Research, USA, \texttt{sunj@ucar.edu}  
\textsuperscript{b}Nanjing University of Information Science and Technology

The variational data assimilation system for the WRF-ARW model is among a number of large-scale data assimilation systems that use stream function and velocity potential as momentum control variables. As recent development of the WRF data assimilation is moving toward the convective-scale applications, we ask the question whether the control variables of stream function and velocity potential are appropriate for domains with limited size and fine grid spacing. In this paper, we compare the background error characteristics of this pair of control variables with that of eastward and northward velocity components and their relative impacts on high-resolution analysis and convective forecasting. The background error characteristics that are examined include the correlation between the control variables and the closeness to Gaussian error distribution. Single observation experiments are conducted to examine the responses of variance and length scale. Finally, a real data experiment is conducted to investigate their impacts on the variational analysis and convective forecasting.
Multi-Scale Data Assimilation of the June 13, 2010 VORTEX2 Tornadic Supercell

Therese E Thompson\textsuperscript{a}, Glen Romine\textsuperscript{b}, Louis J. Wicker\textsuperscript{c}, Xuguang Wang\textsuperscript{a}, and David Dowell\textsuperscript{d}

\textsuperscript{a}School of Meteorology, University of Oklahoma, USA, Terra.Thompson@noaa.gov, \textsuperscript{b}Mesoscale and Microscale Meteorology, NCAR, USA, \textsuperscript{c}National Severe Storms Laboratory, NOAA, USA, \textsuperscript{d}Earth System Research Laboratory, NOAA, USA.

On June 13, 2010 VORTEX2 collected observations in the eastern Texas and Oklahoma Panhandles. Convection developed early in the afternoon on the cool side of an approximately South-Southwest to North-Northeast boundary. The sub-severe convection slowly moved to the Northeast. An approximately east-west outflow boundary was also present from overnight convection. One storm, located near the intersection of the two boundaries, intensified and became tornadic. The complex mesoscale environment and the tornadic storm were not captured well with conventional observations.

The WRF model and DART assimilation system are used to obtain an accurate representation of the mesoscale environment that produced the tornadic storm. Data assimilation cycles every six hours beginning four days prior to the event were performed on a 15 km horizontal grid covering the contiguous US with a 3 km horizontal grid nest over the convective region. These analyses capture the large-scale flow pattern however, do not contain an accurate representation of the mesoscale boundaries.

More frequent cycling is done on the 13\textsuperscript{th} to determine which observations and at what frequency is data assimilation required to capture the boundaries in the environment. Hourly data assimilation cycles beginning at 0 UTC on the 13\textsuperscript{th} improve the analyzed mesoscale environment. The inclusion of radar observations in the hourly cycling produces an environment that supports rotating storms. If the hourly cycling is started later in the day, at 12 UTC, the environment does not fit the observations as closely. This result indicates the importance of assimilating observations of the overnight convection in order to reproduce the observed boundaries. Sensitivity of the forecast skill to the mesoscale environment reconstruction will be presented. The environment will be verified against conventional observations as well as special observations collected during VORTEX2.

The mesoscale background is used to nest down to a 1 km storm-scale grid. The environment and storm forecasts are further refined on the storm-scale with finer observations and more frequent cycling. Preliminary storm forecasts will also be presented.
Early studies of storm-scale radar data assimilation (DA) have shown promising results using the Ensemble Kalman Filter (EnKF [1]) [2,3,4]. However, studies using real data cases in complex heterogeneous environments are still very limited. Successful assimilation and prediction of such cases will require the assimilation of observations at multiple scales so that both the storm itself and its associated environment can be analyzed properly. One advantage of the EnKF compared to computational inexpensive 3DVar is its ability to estimate the error covariances at multiple scales flow-dependently through the ensemble covariances. The GSI-based EnKF has contributed to improve the global forecasts by GFS and hurricane forecasts by HWRF through the hybrid data assimilation system. The goal of this study is to extend the GSI-based EnKF for the convective storms over the US and explore its viability for Multi-scale data assimilation and prediction via comparing with the GSI 3DVar.

In this study, a nested data assimilation method is used to assimilate multiscale observations, including both conventional and radar data. For the outer domain, conventional observations are assimilated every 3 hours during a 3-day period with a 12km grid spacing. For the inner domain, radar observations are assimilated every 5 minutes during a 3 hour period. The inner domain was run with a convection permitting resolution (4km), which is nested within the last cycle of the outer domain. The outer domain cycle provides the lateral boundary conditions for the inner domain cycle. Ultimately, it is hoped that such an approach can provide a viable framework for a unified, multi-scale, high resolution data assimilation and ensemble forecast system. Two parallel experiments, using the GSI based EnKF and 3DVar respectively were conducted and their results are compared. Both the EnKF and 3DVar were adjusted accordingly for the inner and outer domains where different scales were resolved.

A case study characterized by initially small storms that grow into a mesoscale convective system during the forecast period was adopted first. During the assimilation period, first guess innovations using GSI-based EnKF consistently outperform those using GSI based 3DVAR for both the outer and inner domain. The improved performance of EnKF is attributed to the more physically realistic flow-dependent and cross-variable error covariance. The advantage of EnKF is also reflected in a more accurate forecast of the evolution of the initial storms that develop into an MCS.

References
A Simple Dynamical Model of Cumulus Convection for Data Assimilation Research

Michael Wuersch\textsuperscript{a,b}, George C. Craig\textsuperscript{a,b}

\textsuperscript{a}Hans-Ertel-Centre for Weather Research, Data Assimilation Branch, Ludwig-Maximilians-Universitaet, Muenchen, Germany michael.wuersch@lmu.de, \textsuperscript{b}Meteorologisches Institut, Ludwig-Maximilians-Universitaet, Muenchen, Germany,

A simplified model for cumulus convection has been developed, with the aim of providing a computationally inexpensive, but physically plausible, environment for developing methods for convective-scale data assimilation. This model is part of a hierarchy of models, where a stochastic toy model \cite{Craig2013} already exists and is the first in a series of models. The model presented here is an intermediate model. An idealised convection resolving model is the last step of the hierarchy.

Key processes, including gravity waves, conditional instability and precipitation formation, are represented, and parameter values are chosen to reproduce the most important space and time scales of cumulus clouds. The model is shown to reproduce the classic life cycle of an isolated convective storm. When provided with a low amplitude noise source to trigger convection, the model produces a statistically steady state with cloud size and cloud spacing distributions similar to those found in radiative-convective equilibrium simulations using a cloud resolving model. Results are also shown for convection triggered by flow over an orographic obstacle, where depending on the wind speed two regimes are found with convection trapped over the mountain, or propagating downstream.

The model features prognostic variables for wind and rain that can be used to compute synthetic observations for data assimilation experiments. These observation can mimic radar and radial wind observations. An LETKF is used for the data assimilation experiments which will also be presented.

References
The Local Analysis and Prediction System (LAPS) pioneered hotstart data assimilation two decades ago. About 150 groups use LAPS worldwide for analyzing and predicting convective weather events. The traditional, mostly uni-variate analysis scheme in LAPS has been reformulated and the basic variables are now assimilated using a modern variational scheme with a state-of-the-art multigrid numerical computational technique. The new variational LAPS uses reflectivity and analyzed clouds in a hot-start analysis with vertical velocity and humidity. Numerical forecasts initialized with LAPS demonstrate an advantage in the 0-3 hour lead time range over forecasts initialized with more traditional, operationally available analysis products and are competitive with simple statistical nowcasting schemes such as persistence and advection. Ongoing and planned development work will also be reviewed. The performance of LAPS will be demonstrated through case studies of various severe convective weather events, including the Windsor Tornado (2008), cases from the Experimental Warning Program of the Hazardous Weather Testbed (HWT) of NOAA, and real time CONUS scale analyses and forecasts.
Multiscale Ensemble Data Assimilation and Forecasts of a Tornadic Supercell Storm

Nusrat Yussouf a,b, Jidong Gao b, David J. Stensrud b and Guoqing Ge c
Email: Nusrat.Yussouf@noaa.gov

a Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma
b NOAA/OAR/National Severe Storms Laboratory, Norman, OK, USA
c Center for Analysis and Prediction of Storms, University of Oklahoma

The numerical experiments over the past few years indicate that incorporating environmental variability is crucial for successful convective-scale forecasts [1-2]. To explore the impact of mesoscale environmental variability and its uncertainty to very short-range (0–1 h) convective-scale forecasts, combined mesoscale-convective scale ensemble data assimilation and forecast experiments are conducted for the 8 May 2003 Oklahoma City tornadic supercell storm. Two sets of 36-member WRF-ARW model mesoscale ensemble adjusted Kalman filter (EAKF) data assimilation systems with continuous cycling on a continental United States domain are conducted using either fixed physics or multiple physics parameterization schemes across the ensemble members to provide background environmental conditions. Two 36-member convective-scale ensembles are initialized at 3-km grid spacing, one using background fields from the fixed physics and the other using background fields from multiple physics mesoscale ensemble analyses. Reflectivity and radial velocity observations from four operational WSR-88D radars are assimilated into the convective-scale ensemble members using the ARPS model based three-dimensional variational (3DVAR) data assimilation system for a 40-min period and 1-hr ensemble forecasts are launched.

Comparisons between the two convective-scale ensemble forecasts show that the ensemble with background fields from multiple physics mesoscale ensemble provides more realistic forecasts of significant tornado parameter (STP), dryline location and structure, and near surface variables than the ensemble from fixed physics mesoscale background fields. In addition, the probability of strong low-level mesocyclone track of the tornadic supercell correlates better with the observed rotation track from the multiphysics ensemble than that from the fixed physics ensemble. This suggests that incorporating physics diversity across the ensemble is important to successful probabilistic convective-scale forecast of supercell thunderstorms, which is the main goal of NOAA’s Warn-on-Forecast [3] initiative.

References

Impact of Surface Observations on the Predictability of Landfalls of Hurricane Katrina (2005) with Ensemble-based Data Assimilation

Hailing Zhang and Zhaoxia Pu

Department of Atmospheric Sciences, University of Utah, USA, hailing.zhang@utah.edu

Significant improvements have been achieved for hurricane forecasts over the last two decades. However, only a few of studies have emphasized landfalling hurricanes. There are difficulties in predicting hurricane landfall due to the uncertainties in representing the atmospheric near-surface conditions in numerical weather prediction models, the lack of observations in oceans, and the multiple-scale dynamical and physical processes accompanying storm development.

In this study, we conducted a series of numerical experiments to examine the impact of ensemble-based data assimilation on the predictability of Hurricane Katrina (2005), one of the deadliest disasters in US history. The minimum central sea-level pressure, QuikSCAT ocean surface wind vectors, surface Mesonet observations, airborne Doppler radar-derived wind components, and conventional observations from NCEP are assimilated into an advanced research version of the Weather Research and Forecasting (WRF) model with an ensemble Kalman filter method. Impacts of data assimilation on the analyses and forecasts of Katrina’s track, landfalling time and location, intensity, structure, and rainfall are evaluated. Specifically, in light of the lack of knowledge concerning the impact of surface observations, the effect of assimilating surface observations is examined in detail.

It is found that the assimilation of surface observations can improve the prediction of the hurricane track and structure through modifying low-to-mid level thermal and dynamical fields such as wind, humidity, and temperature. It also results in enhanced low-level convergence and vorticity. However, the single-level surface observations cannot constrain the model to predict reasonable intensities due to their lack of impact on the middle to upper troposphere. When surface observations are assimilated with either radar or other conventional data, obvious enhancements are found in the forecasts of track and intensity, convection and surface wind structures, and quantitative precipitation forecasts during landfalls.

References
AROME-NWC: an adaptation of the meso-scale NWP model AROME to nowcasting

Auger Ludovic\textsuperscript{a}, Olivier Dupont\textsuperscript{b}, Pierre Brousseau\textsuperscript{a}, Susanna Hagelin\textsuperscript{a} and Pascal Brovelli\textsuperscript{b}

\textsuperscript{a} CNRM-GAME/GMAP, CNRS and Météo-France, France, ludovic.auger@meteo.fr, \\
\textsuperscript{b} DP/DPrevi/PI, Météo-France, France.

The increase in computing power makes it possible now to use meso-scale models with a higher refresh rate. In that context a nowcasting system (denoted by AROME-NWC) based on the operational non-hydrostatic model AROME \cite{Seity2011} was developed in order to provide recently updated forecasts to nowcasting systems and forecasters.

First, the strengths and weaknesses of a meso-scale model as regards nowcasting will be discussed and it will be shown how such a model can be modified to cope with the challenges of nowcasting. Then the different choices in the design of AROME-NWC system will be presented. It is important for example to have a model that delivers its forecasts within 30 minutes due to the ranges that are of interest in nowcasting (0-6 hours). One important issue is the limited number of observations that can be used due to the necessary short cut-off time, consequently it was chosen not to cycle the system and to start from an AROME forecast each hour in order to benefit from a background that has seen a maximum number of observations.

The performance of this system has been assessed with a comparison to the operational AROME model through classical scores and cases study. A general increase is to be found linked to the use of more recent observations. Finally the last matter discussed will be about the necessary use of nowcasting diagnostics made from the AROME-NWC, as a matter of fact the important number of forecasts available due to the hourly refresh is of benefit to output products and automatic services for customers, those will help the forecasters with analyzing a large amount of data.

References

Development of an Hourly-Updated NAM Forecast System and Application to the Damaging Summer 2012 Derecho Event

Jacob R. Carley\textsuperscript{a}, Geoff DiMego\textsuperscript{b}, Eric Rogers\textsuperscript{b}, Shun Liu\textsuperscript{c}, Brad Ferrier\textsuperscript{c}, Eric Aligo\textsuperscript{c}, and Matthew Pyle\textsuperscript{b}

\textsuperscript{a}UCAR Visiting Scientist Program, USA, jacob.carley@noaa.gov, \textsuperscript{b}NOAA/NWS/NCEP/EMC, \textsuperscript{c}IMSG

The June 29th, 2012 derecho event began over northwest Illinois as a developing mesoscale convective system at approximately 1500 UTC. By 1900 UTC this system had evolved into a bow echo over central Indiana and produced surface wind gusts as high as 91 mph. The storm maintained its damaging characteristics as it later moved southeastward through Ohio, West Virginia, Virginia, Maryland, and the Washington, D.C. metropolitan area by approximately 0300 UTC on June 30th.

This damaging event was generally not well-forecast by the operational 4 km CONUS-nest North American Mesoscale model (NAM), a property that became more problematic as the event approached. Therefore, this event has since served as a benchmark case for the ongoing development of an hourly-updated version of the NAM forecast system. Unlike the operational system, which updates every three hours, this hourly-updated system also cycles and updates the 4 km CONUS-nest in addition to the 12 km parent domain. Furthermore, a cloud analysis system has been introduced along with a twice-diabatic digital filter step to improve the initialization of cloud thermodynamic and hydrometeor fields. The digital filter not only helps to reduce noise in the early part of the forecast, but also applies a radar-derived latent heating tendency based upon the earlier cloud analysis step to help initialize the cloud fields. Also included are updates to the microphysics parameterization to improve both the forecast and representation of convective storms, storm structure, and storm attributes (e.g. strong surface wind gusts). Results of these tests with a focus on the 4 km CONUS-nest forecast of the derecho event from the hourly-updated NAM forecast system will be presented.
Improved Hydrometeor Simulations Using Cloud Resolving WRF and Multi-Scale Data Assimilation and Augmented Forcing for Single Column Models

Sha Fenga, Zhijin Lib, Yangang Liuc, Wuyin Lin, Tami Totoc, and Andrew Vogelmann

aUCLA Joint Institute for Regional Earth System Science and Engineering (JIFRESSE), USA, sfeng@jifresse.ucla.edu, bJet Propulsion Laboratory, California Institute of Technology, USA, cEnvironmental Sciences Department, Brookhaven National Laboratory, USA

A set of numerical experiments for convective cloud and precipitation cases occurring over the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site have been conducted using the WRF-based multi-scale data assimilation system. This system was developed for the FASTER project to examine the influence of the assimilating ARM surface meteorological observations and Balloon-Borne Sounding (SONDE) profiles along with conventional and satellite radiance data processed by the National Centers for Environmental Prediction (NCEP). In addition to further improvements on meteorological fields, the results demonstrate significant impact of ARM observations on modeled clouds and precipitation. Assessments show that the data assimilation improves the fits of domain-averaged mixing ratios of both liquid- and frozen-phase hydrometeors to satellite observations, the vertical structure of clouds via comparisons to radar reflectivity at the SGP central facility, and the spatial structure and amount of precipitation. Hydrometeor-related quantities derived from the data assimilation system are used to initialize and drive Single Column Models (SCMs). The influences are assessed by comparison of the simulations to those by conventional SCM simulations that do not use the hydrometeor-related quantities derived from the data assimilation system.
Toward the assimilation of the future MTG-IRS data in a fine-scale weather forecast model: Potential benefits

Stephanie Guedj, Florence Rabier and Vincent Guidard

CNRM/GAME, Météo-France and CNRS / EUMETSAT, 42 av Coriolis, 31057 Toulouse, France
stephanie.guedj@cnrm.meteo.fr

The future MTG-IRS (Meteosat Third Generation – Infra-Red Sounder) mission is directed by ESA and EUMETSAT to support regional and convective-scale numerical weather prediction in Europe. This instrument will provide unprecedented information on the temperature and humidity, at high vertical, horizontal and temporal resolution.

However, today’s assimilation systems are not designed to use such a amount of data that will be available from MTG-IRS. One reason is the assumption made on observation errors within the variational systems. In fact, it is wrongly assumed that the error in a radiance observations are independent (in space and wavelength). To neglect such a correlation may result in a degradation of the analysis, so that satellite radiances are thinned spatially and the observation errors are inflated.

The future MTG-IRS data are expected to carry horizontal and inter-channel error correlations. Available data from MSG-SEVIRI and Metop-IASI observations at full resolution were used to quantify these potential correlations following various scenarios. In parallel, MTG-IRS data have been simulated using a radiative transfer model and a set of atmospheric profiles. Simulations/retrievals were evaluated against independent observations/models.

In the framework of an Observing System Simulation Experiment, simulated MTG-IRS observations were assimilated in a special version of the AROME forecast model. Improvements are investigated with respect to standard measures, mainly with respect to precipitation fields and moisture convergence over the Mediterranean sea.
AROME Airport: Nowcasting with a High-Resolution Configuration of the Operational French Meso-Scale AROME Model

Susanna Hagelin\textsuperscript{a}, Ludovic Auger\textsuperscript{a}, Olivier Dupont\textsuperscript{b}, Pierre Brousseau\textsuperscript{a} and Pascal Brovelli\textsuperscript{b}

\textsuperscript{a}CNRM-GAME/GMAP, CNRS and Météo-France, France, susanna.hagelin@meteo.fr,
\textsuperscript{b}DP/DPrevi/PI, Météo-France, France.

AROME Airport is a further development of the AROME-NWC [1] and is designed to provide hourly forecasts with a 500 m resolution for the area around an airport which can help in the planning of the use of the runways, particularly as part of a system to support the dynamic separation of aircrafts.

AROME Airport is intialised by the forecasts from the operational AROME model [2] which provide the initial and lateral boundary conditions for a version of AROME-NWC with the same resolution as the operational model (2.5 km) but run on a smaller domain, where the data assimilation is performed. This data is then used for the intial and boundary conditions of the high-resolution AROME Airport.

In this study we present the first results from AROME Airport at Paris – Charles de Gaulle airport during two test periods; early summer 2011 and autumn 2012. The forecasts from AROME Airport are validated against screen level observations of temperature and wind speed as well as dedicated wind profiler data, available from the observation campaigns during these two periods. The impact of using these profiler data in the data assimilation is also discussed as well as the sensitivity of the data assimilation system of AROME Airport. The performance of AROME Airport is compared to the performance of its coupling model and the operational AROME model.

References

Particle filters have been developed in recent years to deal with highly nonlinear dynamics and non Gaussian error statistics that also characterize data assimilation on convective scales. In this work we explore the use of efficient particle filter (P.v. Leeuwen, 2010) for convective scale data assimilation application. The method is tested in idealized setting, on stochastic models that are designed to reproduce some of the properties of convection, for example rapid development and decay of convective clouds.

The first model is a simplified one-dimensional, discrete state birth-death model of clouds (Craig and Würsch, 2012). For this model, the efficient particle filter that includes nudging the variables shows significant improvement with respect to Ensemble Kalman Filter and Sequential Importance Resampling (SIR) particle filter. The success of the combination of nudging and resampling, measured as RMS error with respect to the 'true state', is proportional to the nudging intensity. Furthermore, even a very weak nudging intensity brings notable improvement over SIR. But the results appear to be highly dependent on the observation density used, and on the simplicity of this model.

Another testbed for the particle filter is a modified version of a shallow water model (Würsch and Craig 2013), which contains more realistic dynamical characteristics of convective scale phenomena. Nudging only the velocity among the three field variables (wind, water 'height' and rain) reveals the particle filter to perform comparably well to a regime where only nudging is used. We show that too strong nudging penalizes the results for the unobserved variables. We further show that the efficient particle filter becomes more accurate for spatially scarce observations, and we investigate the effect of nudging different variable fields.

References:


Development of a New Storm-Scale 4D-Var Assimilation System

Takuya Kawabata\textsuperscript{a}, Kosuke Itob, Kazuo Saitoa, and Yuki Honda\textsuperscript{c}

\textsuperscript{a}Forecast Research Department, Meteorological Research Institute, Japan, tkawabat@mri-jma.go.jp, \\
\textsuperscript{b}Extreme Weather Events Projection Research Team, Japan Agency for Marine-Earth Science and Technology, Japan, \\
\textsuperscript{c}Administration Department, Japan Meteorological Agency, Japan.

The Meteorological Research Institute has been developing a nonhydrostatic 4D-Var assimilation system (NHM-4DVAR; [1], [2], [3]) since 2002. NHM-4DVAR is based on the Japan Meteorological Agency (JMA) Nonhydrostatic Model (JMANHM), and is designed to reproduce and predict MCSs at storm scales. The full model of JMANHM, which includes three-ice bulk cloud microphysics, is adopted as the forward model. The adjoint model considers perturbations to dynamics and warm rain process. The horizontal resolution of NHM-4DVAR is 2km.

Several assimilation experiments have been conducted for local heavy rainfall cases using NHM-4DVAR. Through these experiments, assimilation methods of advanced observations have been developed (i.e., Doppler radar radial winds [1], precipitable water vapor data derived by the Global Positioning System (GPS) [1], radar reflectivities [2], GPS slant total delay data [3], radial winds by Doppler lidar [4]), and positive impacts of these data on the forecasts of local heavy rainfall events have also been confirmed.

On the other hand, JMA has operated an operational mesoscale nonhydrostatic 4D-Var assimilation system (JNoVA; [5]) since April 2009. JNoVA has several advantages to NHM-4DVAR (e.g., a wide assimilation area, a penalty term, physical processes), but its horizontal resolution is 15 km.

Development of a new unified assimilation system of NHM-4DVAR and JNoVA is underway for application to the storm-scale assimilation. The new assimilation system implements advanced observation operators, a penalty term, optimizing procedure for lateral boundary conditions, cloud microphysics based on the warm rain process, and other physical processes. The tangent linear, and adjoint models have already been developed, and the framework of the 4D-Var system has been almost fixed. A result of a data assimilation experiment with actual observations will be presented in the symposium.

References

Convective-Scale Data Assimilation

Dale M. Barker

Data Assimilation and Ensembles Section, Weather Science, Met Office, UK.

Data assimilation at convection-permitting scales presents a number of fundamental challenges. Typically, convective-scale events develop on short timescales ranging from minutes to hours. It is therefore important to have both observations that sample fine-scale weather at high time-frequency (e.g. radar) as well as models that can accurately represent the important processes (e.g. convection, cloud physics, etc). Data assimilation techniques need to take account of nonlinearities and complex error structures of both observations and high-resolution models. Operational analyses need to be produced within a very short period of time, e.g. a few minutes if required for nowcasting severe convection.

This talk will provide an overview of the major fundamental challenges for convective-scale data assimilation, followed by a brief description of current and planned future data assimilation capabilities both at the Met Office and elsewhere. In parallel with the development of data assimilation techniques for convective-scale, a wide array of high temporal/spatial resolution observation types are being assessed/under development for application in km-scale NWP. These will be reviewed. Results from recent high-resolution observation system (OSEs) experiments will be presented, giving an indication of relative impact in high-resolution UK data assimilation.

The Met Office showcased a number of new capabilities during the London Olympics period (July-August 2012) in preparation for potential future operational implementation. These included a) A 2.2km/12 member convective-scale Ensemble Prediction System (MOGREPS-UK) to provide uncertainty information for DA and forecasting severe weather, and b) An hourycycling 1.5/3km 4D-Var NWP-Nowcasting Demonstration Project (NDP). The talk will end with an update on plans to bring both these demonstrators into operations.
Forecast errors at convective scale

Thibaut Montmerle
Météo-France CNRM-GAME/GMAP
Toulouse, France

Despite the use of a limited domain, the high computational cost of Numerical Weather Prediction (NWP) systems at convective scale explains why most of the existing operational configurations are still based on variational Data Assimilation (DA) methods that make use of climatological background error covariances, computed for instance off-line from ensembles of background perturbations. However it will be shown that, either for classical model variables or hydrometeors, such errors strongly depend on the weather types and that different spatial covariances and coupling relationships can be found in specific areas (e.g. clouds and precipitation). Flow dependency is thus needed to optimize the use of observations (such as radar data or cloudy radiances) in these areas where the climatological hypothesis is clearly unadapted.

Using a large Ensemble Data Assimilation (EDA) at convective scale coupled with a large EDA at global scale, based respectively on the AROME and on the ARPEGE NWP systems, the flow dependency of background error parameters, such as the variances and the Hessian tensor of the local correlation, will be illustrated. Compared to results at global scale, heterogeneous and anisotropic features, that are linked for instance to the explicit resolution of convective processes or to the lateral boundary conditions, are frequently observed. These behaviours can eventually be considered partially or totally in the background error modelling while running small EDA, provided that sampling noise is efficiently reduced. The shapes of correlation functions at the origin given by the tensor give also an insight of the type of localization procedures that should be applied in ensemble-based DA methods.

This large ensemble has been also used to validate a method, based on the vertical deformation of climatological values, aiming in producing multivariate background error vertical covariances for hydrometeor contents in different cloudy conditions. The characterization of such covariances is indeed essential to take into account observations related to clouds and precipitation, whose assimilation is made possible thanks to the explicit treatment of convection and the detailed microphysical parameterization which allow to represent realistically their simulated counterparts. For the purpose of illustration, an application of such covariances for the assimilation of cloudy IASI radiances in a 1Dvar will be presented.