ISDA 2018

Oral Presentations

Monday

2.1 KEYNOTE: Development and research of GSI-based EnVar for convective scale radar data assimilation: challenges and recent progress

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Convective-scale data assimilation (DA) poses great challenges due to the intermittent nature, smaller spatial and temporal scales of the phenomena themselves; involvement of multiple scales and their interactions; and nonlinearity of the observations and priors. This presentation discusses recent development and research of the GSI-based EnVar for convective scale radar DA. Issue associated with the nonlinear reflectivity operator is first discussed. When hydrometeor mixing ratios are used as state variables, large differences of the cost function gradients with respect to the small hydrometeor mixing ratios and wind prevent efficient convergence. A new method is proposed and implemented in GSI-EnVar. The new method directly adds the reflectivity as a state variable, avoiding the tangent linear and adjoint of the nonlinear operator and therefore resolves the issue. This method is implemented for three US operational convection-allowing regional prediction systems including HRRR, NAM-CONUS and WoF. The effect of the new method is demonstrated and systematically evaluated with a variety of warm season convective scale phenomena. Challenges associated with nonlinearity are also manifested in ensemble based convective scale targeted observation. The ability of the technique to provide meaningfully insight into scanning strategies is investigated with the multi-function phased array radar (MPAR) and tornadic supercells. The results show advantages to utilizing the targeting algorithm for sub-hour convective scale forecasts. Accurate prediction of tornado-like-vortices (TLV) requires depicting the internal structure of thunderstorms in the analysis. Therefore radar DA at the sub-kilometer resolution is needed. Due to the expense of running sub-kilometer background ensembles, a dual resolution EnVar system is developed to produce the analysis at a sub-kilometer grid where a high resolution (HR) analysis is produced (e.g., sub-kilometer) ingesting a low resolution background ensemble, avoiding the need of a costly HR ensemble. Impact of sub-km analysis on TLV simulations and maintenance is discussed.

2.2 Direct assimilation of 3D radar reflectivities with an ensemble-based data assimilation system

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Co-Authors: Axel Seifert, Ulrich Blahak

The assimilation of radar reflectivities at the Deutscher Wetterdienst is currently done by perturbations of the temperature field, via latent heat nudging (LHN). The new ensemble-based data assimilation system COSMO-KENDA allows for directly assimilating radar reflectivities in a more natural way, because it modifies all simulation fields based on the correlations of the ensemble. However, our first experiments did not show a clear improvement over LHN, which could be related to the complexities of COSMO-KENDA. We will discuss the challenges of assimilating radar reflectivities with COSMO-KENDA, and the different methods that we are testing to overcome these challenges. The experiments are evaluated by comparing 6-hours forecast results with radar, surface-station and radiosonde measurements. We focus on the period May-June 2016 over Germany, during which several severe storms were observed. Our new COSMO-KENDA setup clearly outperforms the original one and even improves LHN in some scores.

2.3 Direct Variational Assimilation of Radar Reflectivity and Radial Velocity Data: Issues with Nonlinear Reflectivity Operator and Solutions

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Studies have shown that the assimilation of radar data is helpful for convective-scale numerical weather prediction. So far, the assimilation of reflectivity data has been achieved using either ensemble Kalman filter or indirect methods such as complex cloud analysis or via pre-retrieval of hydrometeors. To directly assimilate radar data within variational framework, some issues associated with the nonlinearity of the reflectivity operator arise When using hydrometeor mixing ratios as the control variables (CVq), the gradient of the cost function can become dominantly large, making the assimilation of reflectivity in storm regions and of radial velocity ineffective. To address this issue, a lower limit on hydrometeor mixing ratios or equivalent reflectivity (qLim or ZeLim) is imposed on the reflectivity observation operator. In addition, a separate analysis pass (VrPass) is used to assimilate radial velocity. When logarithmic hydrometeor mixing ratios are used as the control variables (CVlogq) instead, the issue of the extremely large gradient is avoided. However, the analysis increments are inappropriately spread. As a solution, a lower limit is added to the background when converting the log(q) increment to q increment(XbLim). Through perfect-model observing system simulation experiments for a simulated supercell storm, the capability of directly assimilating radial velocity and reflectivity within 3DVar or En3DVar frameworks using CVq and CVlogq are examined. The results indicate that the analysis and forecast from En3DVar using CVq with ZeLim treatment are closest to the truth. The 3DVar using CVlogq with XbLim produces better analyses of the storm intensity and has faster minimization convergence speed than using CVq. However, with the VrPass treatment, the storm analyses of 3DVar using CVq are greatly improved, and its prediction of storm location is better than using CVlogq.

2.4 Assimilation of GPM/DPR in Km-scale Hybrid-4DVar system

Main Author: Yasutaka Ikuta
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A new km-scale hybrid-4DVar data assimilation system is being developed to improve short-range precipitation forecasts at the Japan Meteorological Agency. One of the purposes of developing this system is to enable the assimilation of high spatial and temporal resolution observations related to hydrometeors. For assimilation of such observation, a new simplified 6-class 3-ice 1-moment bulk cloud microphysics scheme suitable for the tangent linearization has been developed. In addition, the background error covariance of hydrometeors is constructed using ensemble perturbations because the vertical error correlation depends strongly on meteorological situations. Using this km-scale hybrid-4DVar data assimilation system, the impact of Dual-frequency Precipitation Radar (DPR) on board the Global Precipitation Measurement (GPM) core satellite has been investigated. The DPR instrument was developed by the Japan Aerospace Exploration Agency (JAXA) in cooperation with the National Institute of Information and Communications Technology (NICT). This space-borne precipitation radar can observe three dimensional distribution of reflectivity all over the earth. The result of GPM/DPR assimilation experiment will be presented.

2.5 Towards the Assimilation of Radial Winds in an Ensemble Kalman Filter on the Convective Scale

Main Author: Elisabeth Bauernschubert
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Co-Authors: Klaus Stephan, Christoph Schraff, Hendrik Reich, Ulrich Blahak, Roland Potthast

With the Kilometer Scale Ensemble Data Assimilation System KENDA the German Weather Service (DWD) and the Consortium for Small Scale Modeling (COSMO) have developed an Ensemble Kalman Filter for Data Assimilation on the convective scale (c.f. Schraff et al, QJRMS 2016). It is operational at DWD since March 2017. The setup of the KENDA system consists of the ensemble data assimilation system for conventional observations over central Europe in combination with the assimilation of RADAR composits based on latent heat nudging (LHN, Stephan et al 2011).

The new project SINFONY at DWD aims to integrate Nowcasting and NWP in order to develop a seamless integrated forecasting system for the convective scale. A major aspect of this is the incorporation of further high resolution observational sources into the KENDA system like RADAR data from DWD's radar network.

The new weather radar network of DWD includes 17 dual-polarimetric C-Band Doppler radars evenly distributed throughout Germany for complete coverage. The radars offer unique 3-dimensional information about dynamical and microphysical characteristics of precipitating clouds in high spatial and temporal resolutions. First tests on the assimilation of radar reflectivities within the KENDA system have been done by Bick et al, QJRMS 2016. The assimilation is based on the EMVORADO 3D-RADAR forward operator developed by Zheng and Blahak (Zheng et al 2016).

We will present ongoing work on the assimilation of 3D-RADAR radial winds by the KENDA system, based on the EMVORADO forward operator. The focus will be on the time period May-June 2016 with severe convective storms over Germany. Previous experiments and statistical evaluations suggest a combination with LHN, superobbing and temporal thinning of the radial winds and concentration on the lower elevations. We will discuss the impact of the assimilation of radial winds on the forecasts of the COSMO model (precipitation and upper air).

2.6 State-dependent Additive Covariance Inflation for Radar Reflectivity Assimilation

Main Author: Sho Yokota
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Direct assimilation of radar reflectivity can correct not only the hydrometeor but also the atmospheric state (e.g., wind, temperature, water vapor) based on the forecast error covariance including inter-variable correlation. This correlation can be given climatologically in three-dimensional variational method (3D-Var) or calculated by the linear model in four-dimensional variational method (4D-Var). However, reasonable estimation of the correlation has not been sufficiently accomplished. In ensemble Kalman filter (EnKF), the correlation can be calculated by ensemble forecasts without the large cost of development. However, the accurate calculation is limited to only the case that the hydrometeor exists at each analysis point in the first-guess fields of multiple ensemble members. To assimilate radar reflectivity based on the more reasonable inter-variable correlation, we propose a new method for adding ensemble perturbations of radar reflectivity produced from the atmospheric state in points where the hydrometeor does not exist in the first-guess fields before assimilation with EnKF. This may be regarded as a kind of the additive inflation (Mitchell and Houtekamer 2000). However, the added perturbations are not given by random sampling but are created based on perturbations of wind, temperature, and water vapor at each analysis point multiplied by their sensitivities to radar reflectivity calculated in the whole computational domain including the rainfall region. Such perturbations are expected to have reasonable correlation with the atmospheric state. To confirm the advantage of this state-dependent additive inflation, we conducted assimilation experiments of the reflectivity of the Meteorological Research Institute advanced C-band solid-state polarimetric radar with the 50-member local ensemble transform Kalman filter (LETKF) for the case of the tornadic supercell on 6 May 2012. As a consequence of the comparison between experiments with and without the state-dependent additive inflation, the assimilation with this inflation improved short-term rainfall forecasts through modifying wind and water vapor.

2.7 Construction of an ensemble nowcasting with use of overlapping assimilation windows

Main Author: Xiaohua Yang
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Recent decades have seen increasingly more frequent occurrence of extreme summer convections in Europe, often characterised by rather small horizontal scales and short life cycles, hence with rather limited predictability. In order to provide timely warning for such high impact weather, development of an NWP based nowcasting system, which assimilates rapidly delivered observation data with frequent update, is necessary. At Danish Meteorological Institute (DMI), a 3D-Var HARMONIE-AROME nowcasting system has been under development, configured on a 750 m grid domain covering Denmark. At present the suite consists of two parallel 2-hour cycled suites, one with basetime at odd hour and another at even hour. It is planned that the system will be expanded in the near future, resulted in a nowcasting configuration with sub-hourly launch interval, e.g. down to about every 10 min. Main observations data assimilated are, among others, rapidly delivered radar reflectivity and aircraft/MODE-S data. The nowcasting system applies similar cycling strategy as featured in DMI's operational 24-member, 2.5 km grid COntinuous Meso-scale Ensemble Prediction System (COMEPS) which is updated each hour around clock. As in COMEPS, the novice feature of such cycling strategy is the use of overlapping assimilation window, which, through a separation of background and first guess in 3DVAR cycling, enables a frequent analysis update while keeping a relatively longer assimilation window for individual members. From comparative studies, it is shown that use of overlapping window offers a good balance to take care of the need of frequent launch for assimilating observation and the need for a sufficiently long window, latter to ensure observation amount and a suppressed spin-up. Moreover, through time lagging, short range forecasts from consecutive base-time can be combined to form nowcasting ensemble, providing probabilistic forecasts in similar fashion as in operational short range EPS.

6.1 KEYNOTE: Parameter estimation beyond the augmented state approach: Expectation-Maximization algorithm

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One standard methodology to estimate physical model parameters from observations in data assimilation techniques is to augment the state space with the parameters. This methodology presents an overall success when estimating deterministic parameters. On the other hand, the collapse of the parameter posterior distribution found in both ensemble Kalman filters and particle filters is a major contention point when one is interested in estimating model error covariances or stochastic parameters. To overcome this intrinsic limitation, I will give an overview on a statistical learning method that combines the Expectation-Maximization (EM) algorithm with an ensemble Kalman filter to estimate statistical parameters that give the maximum of the observation likelihood given a set of observations. Numerical experiments with toy models will be shown, in which the method is applied to infer model error covariances and deterministic and stochastic physical parameters from noisy observations in coarse-grained dynamical models. The algorithms are able to identify an optimal stochastic parameterization with a good accuracy under moderate observational noise. The proposed EnKF-EM is a promising statistical learning method for estimating model error and for constraining stochastic parameterizations in high-dimensional geophysical models.

6.2 The use of stochastic physics in operational global data assimilation with NGGPS-FV3GFS

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The operational global data assimilation system (GDAS) at NCEP has utilized a hybrid ensemble-variational (EnVar) scheme since May 2012. Since the original implementation, the scheme has had an 80-member ensemble at reduced resolution that is cycled along with the full resolution control and updated each cycle with a serial, square root filter (EnSRF, Whitaker and Hamill 2002). The representation of various components of system errors is critically important in order for the ensemble to properly represent the background error covariances. The original implementation utilized a combination of relaxation to prior spread (RTPS, multiplicative) and lagged-forecast pair perturbations added to the ensemble posterior (Whitaker and Hamill 2012). The system has since evolved to supplement and eventually replace the additive perturbations with various so-called stochastic physics parameterizations. The three schemes that are currently used operationally are stochastically perturbed physics tendencies (SPPT), stochastic energy backscatter (SKEB), and stochastically perturbed boundary layer humidity (SHUM).

Here, we will present an update on the use of stochastic physics within the context of the Next Generation Global Prediction System using the FV3-GFS model. Preliminary results as part of a pre-implementation "beta" version will be presented. We will also discuss future directions including modifications to SPPT for perturbing with more granularity rather than total physics tendencies. Finally, we will explore the implications of various stochastic physics choices on the utilization of scale-dependent localization and all-sky radiance assimilation.

6.3 Joint parameter and state estimation with ensemble Kalman filter based algorithms for convective scale applications

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Representation of clouds in convection permitting models is sensitive to NWP model parameters that are often very crudely known (for example roughness length). Our goal is to allow for uncertainty in these parameters and estimate them from data using the ensemble Kalman filter (EnKF) approach. However, to deal with difficulties associated with convective scale applications, such as non-Gaussianity and constraints on state and parameter values, modifications to the classical EnKF are necessary. In this study, we evaluate several recently developed EnKF based algorithms that either explicitly incorporate constraints such as mass conservation and positivity of precipitation, or introduce higher order moments on the joint state and parameter estimation problem. We compare their results to the localized EnKF on a common idealized test case. The test case uses perfect model experiments with the one dimensional modified shallow water model that was designed to mimic important properties of convection.

6.4 A Bayesian approach to non-Gaussian model error modeling

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Co-Authors: Dmitry Gayfulin

A new Bayesian stochastic model Error Modeling Scheme (BEMS) is proposed. The BEMS generalizes the SPPT and, like the SPPT, works at the point-wise level, imposing the spatio-temporal structure by an external stochastic pattern generator.

At each model grid point, the perturbed next-step model variables should be pseudo-random draws from the "target distribution", the conditional distribution of the truth at the next model time step given the data available from the model at the current time step. The latter are postulated to be (i) the model state, (ii) the physical tendency, and (iii) the total tendency. The model state is regarded as the reference point and part of a prior distribution. The two tendencies are treated as data and thus enter a two-term likelihood. The density of the target distribution (the posterior) is, therefore, the product of the three functions. It appears that two of these functions can be objectively estimated from the model data whilst the third function needs to be modeled.

The advantages of the new scheme are the following. First, as compared to the SPPT, the objectively specified components of the BEMS allow to incorporate additional information in the model error simulation scheme and thus reduce the degree of arbitrariness of the scheme. Second, due to the prior, the BEMS guarantees that the perturbed model variables (i.e. the simulated truth) are within their allowable ranges (no negative humidity etc.) and have zero probability density at the edges of the allowable ranges. Third, in contrast to the SPPT, in the BEMS the physical tendency is perturbed even if the model physical tendency is zero. This acts like an additive perturbation component, which can be useful e.g. for triggering convection.

A fast numerical posterior sampling technique is developed. First results for ensemble forecasts with the COSMO model are presented.

6.5 Diagnosing weak-constraint model error forcing and variational bias correction interaction in the ECMWF assimilation system

Main Author: Jacky Farnan
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Co-Authors: Elias Valur Hólm, Heather Lawrence, Niels Bormann, Patrick Laloyaux, Cristina Lupu

ECMWF has recently re-introduced weak-constraint 4D-Var with model error forcing active above 40hPa. During the development it was noted that the first guess departures and bias correction for several instruments were reduced when the weak-constraint formulation was used, particularly for channels peaking in the upper atmosphere. We describe the interaction between model error forcing and variational bias correction (VarBC) and the effect on the mean analysis state. Both the model error forcing and VarBC have spin-up periods of several months but there has been very little research into how they interact and if either dominates over the other. To investigate this we vary three parameters at initialisation; the initial atmospheric state, the model error forcing and VarBC. The initial conditions were taken from a spun-up strong-constraint experiment and/or a spun-up weak-constraint experiment. The model error forcing and VarBC can be cold-started or warm-started at initialisation from a spun-up experiment. As expected the initial atmospheric state was found to have very little influence beyond 10-12 days. Neither the model error forcing nor VarBC spin-up to the same state after several months of experimentation but instead stabilise at a different state. Both the model error forcing and VarBC initialisation were found to influence the mean state in the upper atmosphere 6 months after initialisation. Their influence on the mean atmospheric state is distinct, different in magnitude and in character. The significance and uncertainties in the upper atmospheric state is discussed.

Tuesday

1.1 KEYNOTE: Data assimilation for convective-scale Numerical Weather Prediction

Main Author: Nils Gustafsson
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Fundamental problems and applied methods in data assimilation for convective-scale numerical weather prediction will be surveyed. The methods include variational methods (3D-Var and 4D-Var), ensemble methods (LETKF) and hybrids between variational and ensemble methods (3DEnVar and 4DEnVar). Limitations in the formulation static background error statistics, generally applied in 3D-Var and 4D-Var, is contrasted with the potential of ensemble-based background error constraints. Other assimilation algorithms, like latent heat nudging, are additionally applied to improve the model initial state, with emphasis on convective scales. It will be demonstrated that the quality of forecasts based on initial data from convective-scale data assimilation is significantly better than the quality of forecasts from simple downscaling of larger-scale initial data. The duration of impact depends however on the weather situation, the size of the computational domain and the data that are assimilated. It will furthermore shown that more-advanced methods applied at convective scales provide improvements compared to simpler methods. Challenges in research and development for improvements of convective-scale data assimilation will also be reviewed and discussed. The difficulty of handling the wide range of spatial and temporal scales makes development of multi-scale assimilation methods and space-time covariance localization techniques important. Improved utilization of observations at convective-scale is important. In order to extract more information from existing observing systems of convective-scale phenomena, for example weather radar data and satellite image data, it is necessary to provide improved statistical descriptions of the observation errors associated with these observations.

1.2 On the operational use of the Kilometre-scale Ensemble Data Assimilation (KENDA) at DWD

Main Author: Christoph Schraff
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Co-Authors: Hendrik Reich, Andreas Rhodin, Roland Potthast, Klaus Stephan

A Local Ensemble Transform Kalman Filter (LETKF) data assimilation for convection-permitting NWP has been developed in the framework of a COSMO Priority Project called KENDA (Km-scale ENsemble-based Data Assimilation). In March 2017, this was introduced operationally at the German Weather Service (DWD) to provide the initial conditions both for the deterministic and ensemble forecasts with the convection-permitting model configuration COSMO-DE. As with the former observation nudging scheme, the current operational setup for the LETKF uses only conventional observations (radiosonde, aircraft, wind profiler, surface station data), but is combined with latent heat nudging for the use of radar-derived precipitation rates. The use of KENDA initial conditions was found to have a very clear positive impact on the ensemble forecasts and to also improve the deterministic forecasts of convective precipitation in summer, as shown at the ISDA 2016. However, later tests for winter 2016 / 2017 revealed some problems with low stratus.

Here, we will present major (pre-)operational changes in 2017. The introduction of additive covariance inflation in the LETKF analysis step resulted in clear improvements for the simulation of low stratus. Further, a soft limiter has been imposed on the explicit soil moisture perturbations in order to decrease the excessive ensemble spread in the predicted 2-m temperature in clear-sky conditions during the summer season. Adding Mode-S aircraft data had further positive impact. In addition to these operational changes, we will also give a very brief overview of ongoing projects that deal with additional, high-resolution observation data in view of their future operational use in the KENDA system.

1.3 Assimilation of cloud-affected radiances in idealized simulations of deep convection

Main Author: Josef Schröttle
Institution: Department of Physics, HErZ Data Assimilation, University of Munich
Co-Authors: Martin Weissmann, Leonhard Scheck, Axel Hutt

We assimilate brightness temperature measurements in the infrared water vapor bands with observation system simulation experiments. These experiments offer the opportunity for assimilating cloud-affected radiances in parameter studies in an idealized setup with deep convection. The convection evolves over the course of one day. The first convective clouds form as liquid water clouds and appear in the visible satellite spectral range (0.6 µm). As the affected radiances in the infrared is assimilated directly for water vapor bands. As the convection evolves ice clouds form at higher altitudes. The signature of the ice clouds on cloud-affected radiances in the infrared is assimilated directly for water vapor bands 6.2 µm and 7.3 µm. We apply different observation error models, study sensitivities to filtering observations, and calculate the sensitivity to scale dependent error growth of radar reflectivity Z, wind, temperature, relative humidity, water vapor and cloud ice. We achieve an improvement of radar-reflectivity fields in the first-guess by 30 % when assimilating the water vapor infrared satellite radiances. Short range forecasts of 1 h of the brightness temperature improve significantly up to 50 %. We provide an outlook on assimilating: brightness temperature differences, clouds as binary objects, and cloud-affected radiances in infrared window channels.

4.1 Non-linear, non-Gaussian effects in the ECMWF 4D-Var

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Nonlinearities in the model evolution and in the observation operators, and insufficiently dense or accurate observations may cause the error statistics of a data assimilation system to deviate from the standard Gaussian assumptions. These effects are becoming ever more important as both the resolution of the model and the data assimilation systems increase, and the use of observations with complex, non-linear observation operators becomes pervasive. Incremental 4D-Var, used operationally at ECMWF, deals with non-linear, non-Gaussian effects through successive re-linearizations of the analysis problem and modelling of non-Gaussian priors. We will discuss strengths and limitations of this approach with reference to recent experience in the ECMWF analysis system and the implications of these findings in terms of data assimilation strategy at ECMWF.

4.2 Improving the MOGREPS global ensemble using 4D-ensemble variational data assimilation

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Co-Authors: Neill Bowler, Adam Clayton, Mohamed Jardak, Marek Wlasak, Lucian Anton, Andrew Lorenc

The Met Office's global ensemble prediction system MOGREPS-G uses an Ensemble Transform Kalman Filter (ETKF) to assimilate observational information into the ensemble. We are working towards replacing this with an ensemble of 4D-ensemble variational data assimilations (En-4DEnVar) in order to retire the ETKF software and instead share common code with our deterministic hybrid 4DVar data assimilation system. This will reduce maintenance overheads and enable MOGREPS-G to more easily incorporate deterministic data assimilation developments to produce better ensemble forecasts. Model uncertainties are simulated through a combination of stochastic kinetic energy backscatter, random parameters and additive inflation using an archive of analysis increments, which also contributes an element of bias correction. Sampling errors are countered using: waveband scale-dependent localisation; a combination of relaxation to prior perturbations and relaxation to prior spread; and by increasing the number of ensemble members from 44 to 100. The ensemble is recentred on a weighted combination of the deterministic analysis and ensemble mean. The mean-perturbation method is used to improve the computational efficiency of the En-4DEnVar step, with perturbation minimisations run in parallel using MPI communicators to improve computational scalability and reduce the run-time to below the target of 15 minutes. This upgrade improves the performance of MOGREPS-G for ensemble forecasting and at least matches the performance of our deterministic data assimilation when its forecast perturbations from the ensemble mean are used in hybrid 4DVar. Indeed, the forecast perturbations have already been used as training data for the global static covariances soon to be implemented in our operational suite ahead of the En-4DEnVar implementation planned for 2018.

4.3 Advances in cloud and water vapor analyses within NGGPS-FV3GFS

Main Author: Catherine Thomas
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Co-Authors: Rahul Mahajan, Daryl Kleist, Fanglin Yang

As part of the Next Generation Global Prediction System (NGGPS), NCEP is working towards replacing the spectral dynamical core of the Global Forecast System (GFS) with the Finite-Volume Cubed-Sphere Dynamical Core (FV3). Many changes have been made to the Gridpoint Statistical Interpolation (GSI) analysis system to accommodate the new dynamical core. In this talk, we will detail some of the challenges faced with regards to clouds and water vapor. One of the advances of the FV3GFS is moving the cloud microphysics parameterization from that of Zhao and Carr (1997) to the GFDL microphysics of Chen and Lin (2011, 2013). Unlike the previous scheme, the new microphysics parameterization predicts individual hydrometeor species. We will detail the modifications that needed to be made for the cloud analysis, which is currently computed as a total cloud condensate variable. We will also discuss possible future directions for the cloud analysis within the GSI, including sending individual hydrometeors to the radiative transfer model and producing individual hydrometeor analyses. In addition to the cloud analysis, modifications are being made to the water vapor analysis for the upcoming FV3GFS implementation. The current operational GFS contains excessive stratospheric water vapor. We will present short term mitigation strategies, such as tapering the water vapor increments with height and relaxing to climatology, as well as preliminary results.

4.4 The accuracy of efficient particle filters

Main Author: Peter Jan van Leeuwen
Institution: Department of Meteorology and NCEO, University of Reading, Reading, UK

Particle filters that are not degenerate in high-dimensional systems by construction have been derived. Although they have been successfully applied to high-dimensional geophysical problems, we know that they are biased for infinite ensemble sizes. That limit has no practical value, but there is a desperate need to understand how accurate these filters really are for small ensemble sizes. The reason that the filters work well must be because the bias is smaller than the Monte-Carlo noise, but it is very difficult to make progress through trying to quantify these two from theory.

Instead, we will explore numerical evidence. A high-dimensional highly nonlinear system consisting of a very large number of uncoupled Lorenz 63 models is used to test the performance of a new equal-weight particle filter. The advantage of this set up is that although the system is high-dimensional, with no hidden low-dimensional attractor, and highly nonlinear, we can easily generate the true posterior pdf. We will show that this new equal-weight particle filter can estimate the posterior mean well on this system, with only 20 global particles, where Ensemble Kalman Filters fail. Furthermore, we will investigate how well this particle filter can generate correct postrior pdf shapes, focusing on observing strategies that lead to multi-modal and/or highly skewed cases. In most cases the filter does remarkably well, but sometimes it fails in this extremely difficult problem, and we will discuss initial thoughts on why this happens. If time permits we will discuss extensions to high-dimensional parameter estimation as well.

4.5 On Localized Particle Filters for the Global Weather Prediction Model ICON

Main Author: Anne Walter
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Co-Authors: Roland Potthast, Andreas Rhodin

Most of the state-of-the-art data assimilation methods are based on an implicit assumption on the Gaussianity of the underlying distributions. If the ensemble distribution is strongly non-Gaussian the analysis is known to be strongly sub-optimal. In this case, various other forms of explicit filters are under development. Here we study a particle filter (PF) in the framework of large-scale data assimilation.

The idea is to sample some probability distribution, where then number of samples reflects the local strength of the probability density. It is well-known that in a high-dimensional framework, PFs suffer from so-called filter divergence under the curse of dimensionality. This means that usually only very few of the ensemble members carry all the weight in the assimilation step. This immediately destroys the diversity of the ensemble and leads to useless behavior when applied in an iterative way. To our knowledge, PFs have not yet been used in an operational environment or been applied to an operational weather model.

We have implemented a localized adaptive particle filter (LAPF) within the global operational framework of German Weather Service. Our implementation includes a set of tools to ensure a proper spread control for the ensemble, such that filter divergence can be avoided. Our approach ensures the stability of the PF. We demonstrate the feasibility of the method by running our implementation for a test period of one month with a global, with state space dimension of approximately n=1.5·10^8. A comparison with operational scores shows that the LAPF is able to provide a reasonable atmospheric analysis in a large-scale environment.

The LAPF is an approximation to Bayes formula. We discuss the implicit assumptions and approximation steps made by the scheme and suggest further development steps which can be understood as the realization of a Metropolis-Hastings sampler, i.e. a Localized Markov Chain Particle Filter (LMCPF).

4.6 Nonlinear data assimilation using synchronisation in a particle filter

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Current data assimilation methods still face problems in strongly nonlinear cases. A promising solution is a particle filter, which provides a representation of the model probability density function (pdf) by a discrete set of particles. As the basic particle filter does not work in high-dimensional cases, the performance can be improved by considering the proposal density freedom. A potential choice of proposal density might come from the synchronisation theory, in which one tries to synchronise the model with the true evolution of a system using one-way coupling via the observations. In practice, an extra term is added to the model equations, damping the growth of instabilities transversal to the synchronisation manifold. When only part of the system is observed, synchronisation can be achieved via a time embedding, similar to smoothers in data assimilation.

In this work we propose a fully nonlinear data assimilation framework which consists of two stages: 1) use the new ensemble synchronisation, a time embedding scheme similar to an ensemble smoother or 4DEnsVar, to relax the particles towards the truth. Promising results for this scheme are obtained, as global synchronisation errors reach values smaller than observation errors, even in partly observed systems; 2) combine these efficient particles with an extension of the Implicit Equal-Weights Particle Filter, a particle filter that ensures equal weights for all particles, avoiding filter degeneracy by construction. The performance of the framework is tested in a 16,384-dimensional barotropic vorticity model. Promising results will be shown and the pros and cons of this new idea will be discussed.

4.7 A Hybrid Kalman-Nonlinear Ensemble Transform Filter

Main Author: Lars Nerger
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A hybrid ensemble transform filter is developed which combines a Kalman-filter update provided by the analysis scheme of the local ensemble transform Kalman filter (LETKF) and a nonlinear analysis following the nonlinear ensemble transform filter (NETF). The NETF computes an analysis ensemble from particle weights and has been shown that it can yield smaller errors than the LETKF for sufficiently large ensembles. The new hybrid filter, referred to as Kalman-nonlinear ensemble transform filter (KNETF) is motived from combining the stability of the LETKF with the nonlinear proporties of the NETF to obtain improved assimilation results for smaller ensembles. The KNETF is domain-localized as the LETKF and can hence be applied to high-dimensional nonlinear models. Its performance depends on the choice of the hybridization weight which shifts the analysis solution between the LETKF and NETF analyses. Strategies to adaptively control this weight are discussed and the performance of the hybrid KNETF algorithm is assessed for experiments with the Lorenz-96 model.

5.1 KEYNOTE: Insight and evidence motivating the simplification of dual-analysis hybrid systems into single-analysis hybrid systems

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Co-Authors: Amal El Akkraoui, Fabio Diniz

Many hybrid data assimilation systems currently used for NWP employ some form of dual-analysis system approach. Typically a hybrid variational analysis is responsible for creating initial conditions for high-resolution forecasts, and an ensemble analysis system is responsible for creating sample perturbations used to form the flow-dependent part of the background error covariance required in the hybrid analysis component. In many of these, the two analysis components employ different methodologies, e.g., variational and ensemble Kalman filter. In such cases, it is not uncommon to have observations treated rather differently between the two analyses components; recentering of the ensemble analysis around the hybrid analysis is used to compensated for such differences. Furthermore, in many cases, the hybrid variational high-resolution system implements some type of four-dimensional approach, whereas the underlying ensemble system relies on a three-dimensional approach, which again introduces discrepancies in the overall system. Connected to these is the expectation that one can reliably estimate observation impact on forecasts issued from hybrid analyses by using an ensemble approach based on the underlying ensemble strategy of dual-analysis systems. Just the realization that the ensemble analysis makes substantially different use of observations as compared to their hybrid counterpart should serve as enough evidence of the implausibility of such expectation.

This presentation assembles numerous anecdotal evidence to illustrate the fact that hybrid dual-analysis systems must, at the very minimum, strive for consistent use of the observations in both analysis sub-components. Simpler than that, this work suggests that hybrid systems can reliably be constructed without the need to employ a dual-analysis approach. In practice, the idea of relying on a single analysis system is appealing from a cost-maintenance perspective. More generally, single-analysis systems avoid contradictions such as having to choose one sub-component to generate performance diagnostics to another, possibly not fully consistent, component.

5.2 Observations in convective-scale ensemble data assimilation: Actual and potential impact

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Co-Authors: Martin Weissmann, Stefan Geiss, Takemasa Miyoshi

Current regional forecasting systems particularly aim at the forecast of convective events and related hazards. Most weather centers use high-resolution ensemble forecasts that resolve convection explicitly. Nevertheless, fast error growth on these scales leads to a low predictability. Improving forecasts therefore requires a frequent cycling with observations that are dense in space and time. Modern regional observing system provide various observations that are not exploited yet but applicable for convective-scale data assimilation. Additionally, new mesoscale observation networks could be installed. However, little knowledge exists on what types of observations are most beneficial on which spatial and temporal scales. This information is crucial for deciding on the deployment of new observations, the refinement of existing observing systems and where to put efforts in the assimilation of currently unexploited observations. For this reason, the HErZ research group at LMU investigates the actual and potential impact of observations with focus on the operational convective-scale ensemble data assimilation system of Deutscher Wetterdienst. An ensemble forecast sensitivity to observations (EFSOI) method has been used to evaluate the contribution of various observations to the reduction in forecast error. This provided information about the actual observation impact of already assimilated observations in a six-week high impact weather period in summer 2016. Furthermore, ensemble sensitivity analysis (ESA) has been applied to 12-h forecasts to investigated the potential impact of possible observations. Both approaches consider several different forecast error metrics to calculate the sensitivities and impacts. Ideally, a metric should reflect quantities in which the forecast users are most interested in (e.g. precipitation or surface temperature/wind). Our studies revealed a particular sensitivity of the forecast to surface pressure as well as upper level wind observations. ESA studies with a 1000-member ensemble simulation provided additional information on the temporal and spatial scale of potential impacts.

5.3 Impact of Assimilating Multi-Scale PECAN Field Campaign Observations on the Numerical Prediction of Bores and Bore-Initiated Convection

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The Plains Elevated Convection at Night Field Campaign (PECAN) provided a unique set of observations within the lower troposphere. Their importance for numerical weather prediction (NWP) was studied within a GSI-based convection-allowing ensemble data assimilation system. In particular, this study examined the impact of assimilating PECAN observations from 5-6 July 2015 on the forecast skill of bore-initiated convection, which is deemed to be an important mechanism for the maintenance of nocturnal mesoscale convective systems (MCSs). This impact was investigated separately with respect to the bore, its environment and the subsequent bore-initiated convection in order to address the multi-sale nature of the studied phenomenon.

Several data addition experiments were performed to understand the effect of assimilating different PECAN observations on the forecast quality of the bore and the bore-initiated convection. The latter included observations from the Atmospheric Emitted Radiance Interferometer (AERI), aircraft, surface, lidar, wind profiler and sounding instruments. The majority of these observation types exerted positive impact on the bore forecast, especially with respect to the environmental conditions in which the bore developed. On the other hand, improvements to the convective part of the forecast were only evident in the numerical simulations utilizing AERI data. The impact of PECAN observations in this case study was shown to be relatively short-term, which has some important implications for the predictability of the studied phenomenon. The aim of this presentation is to not only overview the subjective and objective aspects of the aforementioned results, but also to further explain how the PECAN observations were able to improve the forecast results from both dynamical and thermodynamical points of view.

5.4 The downstream impact of dropsonde and extra radiosonde observations conducted during the NAWDEX field campaign in 2016

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Co-Authors: Martin Weissmann, Andreas Schäfler, Gabor Radnoti

Dropsonde observations from three research aircrafts in the north-Atlantic region as well as several hundred additionally launched radiosondes over Canada and Europe were collected during the transatlantic field campaign NAWDEX in autumn 2016. In addition, over 500 dropsondes were deployed during NOAA's SHOUT and Reconnaissance missions in the west-Atlantic basin, complementing the conventional observing network for a total of 13 intensive observation periods. This unique dataset was assimilated within the framework of cycled data denial experiments performed with the global model of the ECMWF. Routinely computed data assimilation diagnostics such as forecast sensitivity to observation impact and first guess departure are evaluated in addition to results obtained from the deterministic data denial OSE. The presented approach enables an investigation of the observational impact on downstream weather evolution as well as an evaluation of model errors and their potential sources as related to specific weather features such as warm conveyor belts. Results so far suggest a superior forecast performance when additional observations are taken into account, with both dropsonde and additional radiosonde observations exhibiting an overall beneficial impact on the evolution of the short-range forecast error.

5.5 Observation impact diagnostics in an ensemble data assimilation system

Main Author: Olaf Stiller
Institution: Data Assimilation, DWD, Germany

Observation impact diagnostics have been developed to assess the impact of subgroups of observations in the data assimilation (DA) process without the need of performing data denial experiments. These diagnostics are based on a cost function which measures the observation impact with respect to some verifying "truth".

Here (as in Kalnay et al. 2012) such diagnostics are used for an ensemble system, the LETKF/ENVAR system of the DWD's global Icon model. As in Sommer&Weissmann (2016), observations are used for the verifying "truth". In a first step, the method is applied to well established observations like radio sondes, radio occultations and AMSU A radiances and, to avoid ambiguities between assimilation and model issues, the investigation focuses on impacts on the analysis (not on the forecast).

It is shown that the cost function can be split into two components one of which should have expectation value zero if the analysis was optimal (as measured by the cost function). The other component is strictly negative if the observations are pulling the model state closer to the verifying "truth". While the first component yields an optimality condition for the DA process, the second component shows the consistency between analysed observations and the verifying truth (here other observations).

For the well established observations considered here, the overall consistency is found (second criterion) to be generally quite good. Exceptions are some AMSU A channels for which bias problems could be identified in some regions. From the optimality condition (first criterion) radio sondes and radio occultations seem to be well employed but AMSU A seems to be assimilated with a far to strong weight by the DA system.

The aim of this work is to establish a well understood diagnostic tool which helps identifying observation subgroups whose usage is sub optimal in our DA system.

Wednesday

1.4 Mesoscale dynamical regimes and balance in convective-scale DA

Main Author: George Craig
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Co-Authors: Tobias Selz

Different dynamical regimes in the atmosphere are identified by comparing the magnitude of terms in the governing equations in a seven day, convection permitting simulation of weather over Europe and the eastern Atlantic Ocean. As expected, geostrophic balance holds approximately on large scales and hydrostatic balance is valid over a wide range of the mesoscale. Interestingly, for a wide range of scales from about 10 to 500 km, the atmosphere approximately satisfies a form a weak temperature gradient balance, where vertical motion is determined by the requirement that adiabatic cooling approximately equals diabatic warming. The accuracy of this balance is less than that of geostrophic balance on synoptic scale, but to the extent that it holds, it allows a distinction between divergent motions driven by convective clouds and those associated with transient gravity waves, and may represent a useful constraint for convective-scale data assimilation.

1.5 The Met Office hourly 4D-Var system, status and plans

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Co-Authors: Bruce Macpherson, Gareth Dow, Gordon Inverarity, Robert Tubbs, Marek Wlasak

In July 2017, the operational Met Office UKV model moved from 3-hourly 3D-Var to hourly cycling 4D-Var. The hourly cycle allows the model to assimilate observations and generate new short-period forecasts more frequently, while 4D-Var generates a flow dependent assimilation method. In introducing the hourly cycling, we were obliged to shorten the observation cut-off time from 75 to 45 minutes, which led to the loss of some key observations, particularly lower tropospheric radiosonde data. The loss of such data does have a detrimental impact on the longer forecasts. A test version will allow a longer cut-off on cycles with more radiosonde data.

Improvement of the observational input to UKV 4D-Var is always a priority. The latest version now assimilates roadside visibility observations to supplement the already valuable impact of roadside temperature and humidity data. Better short-period visibility forecasts are of interest, for example, to aviation customers. Mode-S aircraft data are also under test and available from an increasing number of UK airports. Wind reports are of similar quality to AMDARs while the temperature data available in the UK are of lower quality.

Developments in the background error covariance matrix (B) are also under review. To date the UKV has used covariances computed using the lagged NMC method. Those currently operational were derived from (t+6-t+3) forecast differences in 3-hourly 3D-Var trials. Since moving to an hourly cycle, tests of shorter forecast lead times and smaller lead time differences within the NMC method have been done. However they are not yet competitive with the operational B. New methods are under study, including a hybrid 4D-Var technique using the convective-scale ensemble.

1.6 Development of a storm-scale particle filter for investigating predictability of convection initiation and development

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Co-Authors: Genta Ueno

A particle filter (PF) with the JMA meso-scale nonhydrostatic model (JMANHM; NHM-PF) has been developed in 2017. The aim is to study predictability of convection initiations and developments with weak forcings. In general, convections without strong forcings (e.g., cold fronts, tropical cyclones, mountains) seem to be initiated randomly. Then, it is difficult to detect exact factors for the initiations. Moreover, PDFs of these predictability are thought to be non-Gaussian, which has made it difficult to predict and even investigate such phenomena, so far. While, it is able to deal with the non-Gaussianity when PF is applied for these researches. The NHM-PF employs a sampling importance resampling (SIR) filter with advanced observations such as GNSS integrated water vapor, dual polarimetric radars and conventional observations provided by NHM-4DVAR. These rich observations are important to constrain the initiations, but these may be cause of filter collapse. A short assimilation period and introduction of model error should mitigate this collapse. The idea of this study is to investigate non-Gaussianities in environmental fields (winds, temperature, water vapor) before the initiations as well as interior cumulonimbus (cloud microphysics) after the initiations. Detailed descriptions on this study and the NHM-PF will be presented.

1.7 Data assimilation of GNSS Zenith Total Delays in KMA convective scale model

Main Author: Eun-Hee Kim
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Co-Authors: Eunhee Lee, Seungwoo Lee, Yong Hee Lee

The convective scale NWP model Local Data Assimilation and Prediction System, LDAPS) is operational at Korea Meteorological Administration (KMA). The LDAPS model has a resolution of 1.5 km and uses the three dimensional variational (3D-Var) data assimilation scheme with a cycle of 3 hours. For short-range forecasting at a kilometer scale it is important to utilize observations with high spatial and temporal resolution. Atmospheric moisture-related information obtained from Global Navigation Satellite System (GNSS) observations have been firstly used in LDAPS. It is because using Zenith Total

Delay (ZTD) data obtained from a ground-based network of GNSS receivers can fill gap of lacking rapid humidity information to improve the predictability of short-term forecast. Among total about 100 stations over the Korean Peninsula, the 40 ground-based GNSS stations were preferentially utilized and assessed over a one-month summer period. In order to confirm the quality of GNSS data, GNSS-derived precipitable water vapor (PWV) was compared to radiosonde observation. The observation-processing system includes quality control and bias correction for each point. Assimilation of GNSS ZTD resulted in a positive impact on lower tropospheric humidity and rainfall forecasts against radiosonde observations and hourly precipitation observations. Around 100 ground-based GNSS stations can be recently used in near real time by NMSC (National Meteorological Satellite Center)/KMA and are being tested in LDAPS and its impact was evaluated through heavy rainfall case. In addition, in order to remove the correlation between the observation points, it applied to take priority through the estimation of observation error.

1.8 Is 30-second update fast enough for convection-resolving data assimilation?

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Co-Authors: Juan Ruiz, Guo-Yuan Lien, Toshiki Teramura, Yasumitsu Maejima, Keiichi Kondo, Hideyuki Sakamoto

For local severe weather forecasting at 100-m resolution with 30-minute lead time, we have been working on the “Big Data Assimilation” (BDA) effort for super-rapid 30-second cycle of an ensemble Kalman filter. We have presented two papers with the concept and case studies (Miyoshi et al. 2016, BAMS; Proceedings of the IEEE). Since then, we have performed more experiments in multiple torrential rain cases, and all showed promising results. We were hoping that we could assume the Gaussian error distribution in 30-second forecasts before strong nonlinear dynamics distort the error distribution for rapidly-changing convective storms. However, using 1000 ensemble members, the reduced-resolution version of the BDA system at 1-km grid spacing with 30-second updates showed ubiquity of highly non-Gaussian PDF associated with convective activities. Although our results so far with multiple case studies were quite successful, this gives us a doubt about our Gaussian assumption even if the data assimilation interval is short enough compared with the system’s chaotic time scale. We therefore pose a question if the 30-second update is fast enough for convection-resolving data assimilation under the Gaussian assumption. To answer this question, we aim to gain combined knowledge from BDA case studies with different cycle intervals, 1000-member experiments with 1-km grid spacing, 4D-EnKF experiments with different window lengths, and toy-model experiments with dense and frequent observations. In this presentation, we will show the most up-to-date results of the BDA research, and will discuss about the question if the 30-second update is fast enough for convective-scale data assimilation.

1.9 Representation of model error in convective scale data assimilation

Main Author: Yuefei Zeng
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Co-Authors: Tijana Janjic, Alberto de Lozar , Ulrich Blahak, Matthias Sommer, Hendrik Reich

The Kilometre-scale ENsemble Data Assimilation (KENDA) system has been run operationally at the Deutscher Wetterdienst (DWD) since March 2017. KENDA uses the Local Ensemble Transform Kalman Filter (LETKF) algorithm to assimilate data for convective scale data assimilation application. To account for large scale model error as well as sampling errors, the multiplicative inflation, additive inflation and the relaxation to prior perturbations (RTTP) method have been implemented in the KENDA.

In this work, we introduce another type of additive inflation based on the model resolution errors, which are samples of differences between two COSMO-DE forecast runs at 1.4 and 2.8 km. The experiments, that assimilate conventional observations and radar reflectivity data, are conducted to investigate those different ways of representing model errors. The experiment with the newly implemented additive inflation results in better analyses during assimilation cycles compared to independent radar velocity data and improved ensemble forecasts up to several hours.

1.10 Assimilation of temperature and humidity profiles from a Raman Lidar

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Co-Authors: Alexander Haefele

MeteoSwiss operates a Raman lidar to measure tropospheric humidity and temperature profiles with high temporal and vertical resolution. The lidar is fully automatic, running unattended and yields a data availability of more than 50% on average. The maximum vertical range is 5 km during day and 10 km asl during nighttime in cloud free conditions. In order to investigate the value of the lidar profile observations in Numerical Weather Prediction, two two-day assimilation experiments with the operational, convective-scale COSMO-LETKF-based data assimilation system of MeteoSwiss (2.2km grid size and 40 members) have been conducted: a case of fog formation in the Swiss Plateau and a case of summer convection. In this contribution, we compare ensemble analyses and forecasts using the operational set of observations from radiosondes, wind profiler, surface stations, aircrafts and radar-derived surface precipitation profile with those, in which the additional, 30min-frequency observations of the Raman Lidar have been taken into account.

8.1 KEYNOTE: Coupled Earth System As-

similation in NWP at ECMWF
Main Author: Phil Browne
Institution: European Centre for Medium-Range Weather Forecasts
Co-Authors: Patricia De Rosnay, Hao Zuo

As part of the long-term strategy, ECMWF will soon use produce all its forecasts using a coupled ocean-atmosphere-land forecast model. Therefore initial conditions for all components need to be supplied. In this talk I will describe how different levels of coupled assimilation are used for the various components of the system.

In the first part of the talk I will focus on the land surface-atmosphere interactions that use a weakly coupled assimilation approach. I will discuss the impacts and future plans for snow and soil moisture analyses at ECMWF.

As a first step towards having a consistent analysis across the atmosphere and the ocean components, weakly coupled data assimilation (WCDA) has been implemented. In this talk I will describe the impact of WCDA through the transfer of fields such as sea-ice concentration and ocean currents from the ocean analysis to the atmosphere. Further I will discuss WCDA through sea surface temperature (SST) and why we choose to limit this to the tropics and not the extra-tropics.

In parallel a stronger form of coupled analysis has been developed - Quasi-strongly coupled assimilation (or outer loop coupling). I will show results that suggest improvements from this stronger form of coupling extend further into the atmosphere than by using WCDA, but discuss the challenges that need to be overcome to make this an operationally viable method.

8.2 COUPLED DATA ASSIMILATION WITH TERRSYSMP

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The Terrestrial Systems Modeling Platform (TerrSysMP) consists of component models for the atmosphere (Consortium for Small-Scale Modeling; COSMO), the land surface (NCAR Community Land Model; CLM) and subsurface (ParFlow) to improve our understanding of time-space patterns of energy, water and carbon fluxes and feedbacks in the terrestrial system. TerrSysMP uses an external coupler (OASIS3 coupler interfaced with MCT; OASIS3-MCT). Predictions with TerrSysMP are affected by random and systematic errors, which in part are related to the many uncertain input parameters and forcings. The data assimilation frameworks PDAF and DART have been coupled to TerrSysMP, which allow a correction of model states and parameters by real-time measurements. With TerrSysMP-PDAF up to 10^8 unknown states and parameters can be estimated, for each of the 10^2 ensemble members. The TerrSysMP-PDAF and TerrSysMP-DART frameworks have been tested in a series of synthetic and real-world experiments ranging from the hillslope scale to the continental scale, and for the assimilation of different data types like soil moisture, soil temperature, groundwater levels, river water levels and boundary layer temperature profile. In the presentation three examples will demonstrate the potential of data assimilation in combination with TerrSysMP, with a focus on coupled data assimilation.

8.3 Assimilation of land surface temperature in the coupled land atmosphere system

Main Author: Christine Sgoff
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Co-Authors: Annika Schomburg, Juerg Schmidli

The near-surface weather and climate variability is strongly influenced by complex interactions between the land surface and the atmospheric boundary layer. To obtain realistic boundary layer simulations an accurate simulation of the coupling between land surface and boundary layer atmosphere is essential. To improve the simulation of this tightly-coupled system, an observing system simulation experiment (OSSE) is designed to assimilate land surface temperature (LST) derived from geostationary satellites. LST is an important component of the surface energy balance and crucial for the realistic simulation of soil temperature, latent and sensible heat flux. As “Nature Run” a high-resolution COSMO simulation has been performed and from this “true state” the synthetic observations for the OSSE have been derived. The assimilation process is based on the local ensemble transform Kalman filter (LETKF). Technically this is realized by the LETKF framework used at DWD (KENDA, Schraff et al. 2015). Within this idealized setting, the impact of hourly LST assimilation on soil and lower atmosphere variables and processes will be investigated. To gain improved knowledge about boundary layer processes and evolution, idealized experiments with different surface characteristics and boundary layer regimes will be conducted. First results will be presented.

8.4 Use of satellite soil moisture information for Nowcasting-Short Range NWP forecasts

Main Author: Paride Ferrante
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Co-Authors: Francesca Marcucci, Lucio Torrisi, Valerio Cardinali

Many physical, chemical and biological processes taking place at the land surface are strongly influenced by the amount of water stored within the upper soil layers. Therefore, many scientific disciplines require soil moisture observations for developing, evaluating and improving their simulation models. One of these disciplines is meteorology where soil moisture is important due to its control on the exchange of heat and water between the soil and the lower atmosphere. The assimilation of soil moisture observations and the development of an algorithm to initialize soil moisture is crucial to improve the forecasts of low level air temperature and humidity: if not suitably constrained, the soil moisture in a numerical model will drift from the true climate, resulting in erroneous boundary layer forecasts. An operational soil moisture product is generated by HSAF from the Advanced Scatterometer (ASCAT), that is a C-band active microwave remote sensing instrument flown on board of the METOP satellite series. The aim of the present work is to assimilate the HSAF soil moisture data with the COMET ensemble data assimilation system, based on the LETKF algorithm, in order to influence not only the soil parameters, but also the near surface atmospheric fields. The HSAF soil moisture observations have been operationally monitored since January 2015, in order to perform data quality control, bias correction and to investigate different approaches to define a suitable observation operator. A preliminary version of soil moisture LETKF assimilation has been developed in the COSMO-KENDA (Kilometre-scale ENsemble Data Assimilation) scheme. An experimental suite has been also implemented, in order to evaluate the impact of HSAF soil moisture data assimilation and to assess how the analysis scheme could be improved.

8.5 Treating sample covariances for use in strongly coupled atmosphere-ocean data assimilation

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Co-Authors: Polly J. Smith, Nancy K. Nichols

Covariance information derived from an ensemble can be used to define the a priori atmosphere-ocean forecast error cross covariances required for variational strongly coupled atmosphere-ocean data assimilation. Due to restrictions on sample size, ensemble covariances are routinely rank deficient and/ or ill-conditioned and marred by sampling noise; thus they require some level of modification before they can be used in a standard variational assimilation framework. Here, we compare methods for improving the rank and conditioning of multivariate sample error covariance matrices in the context of strongly coupled atmosphere-ocean data assimilation. The first method, reconditioning, alters the matrix eigenvalues directly; this preserves the correlation structures but does not remove sampling noise. We show it is better to recondition the correlation matrix rather than the covariance matrix, as this prevents small but dynamically important modes from being lost. The second method, model state-space localisation via the Schur product, effectively removes sample noise, but can dampen small cross-correlation signals. A combination that exploits the merits of each is found to offer an effective alternative.

Thursday

7.1 How does covariance inflation impact EnKF-initialized convection-allowing ensemble forecasts?

Main Author: Craig Schwartz
Institution: The National Center for Atmospheric Research (NCAR)
Co-Authors: Glen Romine, Kathryn Fossell

Covariance inflation is an important component of ensemble Kalman filters (EnKFs) to maintain proper ensemble spread. While different inflation methods have been compared and contrasted in global models, little work has examined how inflation impacts EnKF-initialized convection-allowing ensemble forecasts, which are becoming more common.

To fill this void, four experiments were performed that were identically configured except with regard to their inflation schemes. One experiment employed prior adaptive state-space inflation, while a second used both prior and posterior adaptive state-space inflation. A third experiment employed a combination of prior adaptive state-space inflation and a “spread restoration” method that provides additional inflation during observation assimilation, and the fourth experiment used a state-space “relaxation to prior spread” (RTPS) approach that considerably differs from the adaptive inflation method used in the other three experiments. All experiments used continuously cycling EnKF data assimilation for a 35-day period with 50 ensemble members at 15-km horizontal grid spacing over a limited-area domain, and 15-km analysis ensembles were downscaled to 3-km to initialize 48-hour, 10-member convection-allowing ensemble forecasts over the conterminous United States.

Including spread restoration improved both the EnKF (as measured by prior observation-space statistics) and 3-km precipitation forecast quality. However, the RTPS experiment initialized 3-km precipitation forecasts that were comparable to or better than those initialized by the other three experiments. As the RTPS approach is simpler than the adaptive inflation scheme, these results suggest using RTPS is an attractive method for implementation in EnKFs that initialize convection-allowing ensemble forecasts.

7.2 Predictability of Deep Convection in Idealized Experiments under Radar Data Assimilation

Main Author: Kevin Bachmann
Institution: Hans-Ertel-Centre for Weather Research, LMU, Munich, Germany
Co-Authors: Christian Keil

Increasing computational resources now allow the use of storm-scale ensembles in numerical weather prediction with potentially profound beneficial impact on the prediction of convective precipitation. Therefore, several weather services are developing and evaluating high-resolution, limited-area ensemble prediction systems like COSMO-KENDA at DWD. In this context, the use of spatially and temporally high resolved observations, such as radar data, to provide perturbed initial conditions, becomes increasingly important. The practical predictability limits of convective precipitation in such a state-of-the-art system and their sensitivities to observations are investigated in a perfect model experiment, with only initial condition errors.

For horizontal-homogeneous, convectively unstable conditions favoring long-lived convection, we found skillful predictions for scales as small as 50 km after 8 h lead time. For experiments with fewer observations or larger observation errors, the predictability decreases, but scales above 100 km remain predictable. Additionally, we found that the presence of orography in the experiments increases the predictability, as it acts as a trigger for deep convection. This positive effect decreases with improving quality of the initial conditions for up to 6 forecast hours. Thereafter, the orography exhibits increasing impact on the forecast skill again. Similar experiments with only large-scale initial condition errors or with artificial model error will be performed soon and should provide further insight into realistic initial condition errors and their growth.

7.3 Ensemble initial conditions targeted at the convective scale

Main Author: Jan Keller
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Co-Authors: Clarissa Figura, Andreas Hense

The estimation of fast growing error modes of a system is a key interest of ensemble data assimilation when assessing uncertainty in initial conditions. As initially small-scale error growth structures congregate to large scale structures over time, it is crucial to reintroduce new meaningful perturbations in order to estimate reasonable initial conditions for small-scale forecasting, e.g., forecasting events on the convective scale.

With respect to such uncertainty structures associated with convective scale events and the corresponding forecast error growth, we employ the so-called self-breeding approach. It allows for the estimation of initial ensemble perturbations targeted at maximizing the error growth on convective time scales while taking into account the challenges arising from using a limited area model.

Using this approach, we present results from case study experiments for convective events using the NWP model COSMO in its convection-permitting setup. We also investigate the potential of the obtained uncertainty structures for enhancing the data assimilation process with respect to convection in the model's LETKF data assimilation scheme (KENDA).

7.4 Assimilation of horizontal line-of-sight winds with a mesoscale EnKF data assimilation system over the northern Atlantic and Europe

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Co-Authors: Nedjeljka Žagar, Jeffrey L. Anderson

The forthcoming ADM-Aeolus mission of the European Space Agency will provide global coverage of vertical profiles of horizontal line-of-sight (HLOS) wind twice per day. In previous studies, the potential impact of HLOS winds has been extensively evaluated using the ECMWF variational data assimilation system and a significant impact was reported over the tropics. Over Europe, a minor impact was obtained for short forecast ranges but a positive impact was sustained in the medium range. As part of the preparation for the use of HLOS winds in mesoscale NWP systems in Europe, we shall examine the impact of HLOS winds in an ensemble Kalman filter (EnKF) limited area data assimilation system over Europe and the North Atlantic. The study uses the Weather Research and Forecast model (WRF) and the ensemble adjustment Kalman filter (EAKF) from the Data Assimilation Research Testbed (DART). The Observing System Simulation Experiment (OSSE) framework was developed with a 50-member EAKF nested in the operational 50-member ensemble prediction system of ECMWF using model-level data available twice per day. The importance of the flow-dependent background-error covariances was explored using experiments without covariance inflation. The value of HLOS winds is compared with a single wind component and full wind information. In areas of strong covariances such as along fronts in the Atlantic, multivariate information provides significant analysis increments, especially if the HLOS observation is aligned along the front. It is furthermore shown that the assimilation of wind information in terms of the HLOS component may produce better analyses than the assimilation of either the zonal or meridional winds.

4.8 Exploiting Nonlinear Relations between Observations and State Variables in Ensemble Kalman Filters

Main Author: Jeffrey Anderson
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Serial implementations of ensemble Kalman filters can partially separate the challenges of non-gaussian observation likelihoods and prior probability distributions from those associated with nonlinear relations between state variables and observed quantities. A number of serial algorithms have been developed that deal with non-gaussianity in observation space. There has been less work on dealing with the challenges of nonlinearity and most proposed algorithms have not provided significant improvements in large geophysical applications.

Three methods for computing the ensemble increments for a model state variable given increments for an observation are described and compared. The first is the standard linear regression which is implicitly used in ensemble filters like the EnKF and in the classical Kalman filter. The second method is a rank regression that is appropriate for nonlinear relations that are either monotonically increasing or decreasing as a function of the observed variable. This method extends aspects of the rank histogram filter method that allow arbitrary likelihoods and priors in observation space. The third method incrementally regresses observation space increments onto state variables. The algorithm also incorporates local linear regression. The regression coefficient (analogous to the Kalman gain) for each ensemble member is computed using a subset of the prior ensemble members. Combining local regression with an incremental update allows ensemble filters to compute significantly improved posteriors for a wide range of nonlinear prior distributions with little degradation to solutions for linear cases.

Examples are shown for specific classes of nonlinear bivariate priors and for low-order dynamical systems. A discussion of the relative costs and capabilities of three algorithms is presented. The challenges of recognizing and exploiting nonlinear relations in the presence of noise is highlighted.

4.9 Mixed Gaussian-Lognormal Based Variational Data Assimilation

Main Author: Steven Fletcher
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Co-Authors: Anton Kliewer, Andrew Jones, John Forsythe

An underlying assumption made in most forms of variational and ensemble based data assimilation systems is that the associated errors are Gaussian distributed random variables. However, when dealing with variables that cannot go negative, then it is not always optimal to apply a Gaussian model for the errors. At the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University we have developed a theory that allows for the minimization of the errors that are a combination of Gaussian and lognormal random variables simultaneously. This approach is possible through defining a mixed Gaussian-lognormal probability density function. In this presentation, we shall present details about the mixed distribution and show examples with toy problems, as well as with a 1-dimensional microwave retrieval system for mixing ratio and temperature. We shall also present a new observational quality control measure that would enable lognormally distributed observations errors to be screened to allow for a more consistent method for screening these sets of non-Gaussian observation errors.

4.10 Preservation of physical properties with Ensemble-type Kalman Filter Algorithms

Main Author: Tijana Janjic Pfander
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Co-Authors: Yuefei Zeng, Yvonne Ruckstuhl

In recent work we illustrated benefits of conservative data assimilation procedures in very simple idealized setups designed for convective scale data assimilation as well as in setups more appropriate for global data assimilation. Following the conservation principle, first conservation of mass and preservation of positivity have been shown to be important constraints for data assimilation algorithms. These two constraints have been incorporated into a new algorithm, based on the ensemble Kalman filter (EnKF) and the quadratic programming (QPEns: Quadratic Programming Ensemble filter). For state estimation, the inclusion of the constrained estimation can improve the ensemble Kalman filter results in case of strongly non-Gaussian error distributions. In particular, it was shown that it is important to preserve both positivity and mass in order to obtain good estimates of the fields when the error in location dominates and that the mass conservation- and positivity-constrained rain significantly suppresses noise seen in localized EnKF results.

In the setup more appropriate for the global data assimilation, we extended QPEns algorithm to replicate properties of nonlinear dynamical systems such as conservation of energy and enstrophy. Idealized experiments were performed using a 2D shallow water model, with selected constraints derived from the nature run. Although all experiments exhibited comparable RMSE, the kinetic energy and enstrophy spectra in experiments with the enstrophy constraint (on the globally integrated enstrophy) were considerably closer to the true spectra, in particular at the smallest resolvable scales. Therefore, imposing conservation of enstrophy within the data assimilation algorithm effectively avoids the spurious energy cascade of rotational part and thereby successfully suppresses the noise. The 14-day deterministic and ensemble free forecast, starting from the initial condition enforced by both total energy and enstrophy constraints, produced the best prediction.

9.1 KEYNOTE: Chemical data assimilation

Main Author: Richard Ménard
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Co-Authors: Martin Deshaies-Jacques, Sergey Skachko

Why are we doing chemical data assimilation? There is of course purpose for inverse modeling, monitoring, and forecasting, but another reason perhaps less known, is its application to assess the impact of air pollution on human health – a growing problem as more people lives in urban areas and megacities. Although there are many time scales of atmospheric chemistry from which derive different applications and formulations, common to all lies fundamentally a mass estimation problem. We discuss the properties of mass conservation, on the first and second moments and on the pdf itself. We also discuss its implication to data assimilation and numerical schemes, and discuss chemical assimilation schemes that have been developed specifically to chemical tracers. For atmospheric chemistry as in other applications, the analysis is actually a product by itself. We present a general theory of evaluating analyses by cross-validation, and not through forecasting. The theory generalizes the Desroziers et al. diagnostics where the use of independent observations renders the estimation problem well-posed.

9.2 Recent developments on the ECMWF's CAMS data assimilation suite.

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Co-Authors: Melanie Ades, Antje Inness, Anna Agusti-Panareda, Richard Engelen, Johannes Flemming, Zak Kipling, Sebastien Massart, Mark Parrington, Vincent-Henri Peuch

The European Union's Copernicus Atmosphere Monitoring Service (CAMS) operationally provides daily forecasts of global atmospheric composition and regional air quality. It uses the ECMWF's Integrated Forecasting System (IFS), that includes meteorological and atmospheric composition variables, such as reactive gases, greenhouse gases and aerosols. In this presentation, we will focus on new developments of the system such as: The integration of the new Sentinel-5p satellite that has been successfully launched in October 2017. The sensor provides global-scale high horizontal resolution observations of key components (ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, aerosols and methane). We will show first results of the monitoring of S5p data with the CAMS system. The efforts of updating the system to an Ensemble of Data Assimilation (EDA), i.e. running an ensemble of variational analysis updates and subsequent forecasts. Although the CAMS background error is still formulated using the NMC method, first results are now being produced with the NWP flow dependent background error covariance matrix with seasonal and time dependent variances. Lastly, we will cover the plans and updates on emissions inversions and the challenges to retrieve emission information from satellite data within the IFS. We will show the benefits of using the ensemble information that could be retrieved from the EDA in order to infer sources and potentially separate the inversion sectors e.g. anthropogenic, biogenic, biomass-burning emissions.

9.3 Source identification from image-type measurement data for atmospheric chemistry models

Main Author: Alexey Penenko
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Co-Authors: Zhadyra Mukatova, Ann Blem

The inverse source problems for atmospheric chemistry models with image-type measurement data like concentrations time series or vertical concentrations profiles are considered. The sensitivity operators composed of the sets of the adjoint problem solutions allow to transform the inverse problem stated as the system of ODE or PDE to the family of operator equations depending on the given set of orthogonal functions in the space of the measurement results [1]. The proper choice of the orthogonal functions allows optimizing the dimensionality of the problem thus allowing for the efficient solution of the resulting operator equation with the relevant iterative methods for nonlinear ill-posed operator equations (e.g. the methods based on the truncated SVD). This reduction of the dimensionality can be done by choosing the set of left singular vectors corresponding to the largest singular values of a sensitivity operator, constructed for the largest feasible (for the computer used) number of the orthogonal functions from some general basis (e.g. trigonometric) in the space of the measurement results.

The work has been supported by the RSF project 17-71-10184.

References [1] Penenko A.V., 2018. Consistent numerical schemes for solving nonlinear inverse source problems with the gradient-type algorithms and the Newton-Kantorovich methods. Numerical Analysis and Applications, 2018 (in press).

9.4 Quantitative estimation of volcanic ash emissions and its uncertainty by a combined minimization-particle smoother

Main Author: Philipp Franke
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Co-Authors: Anne Caroline Lange, Hendrik Elbern

Volcanic eruptions may pose a threat to humans, climate, economy, and aviation. For decision makers, the estimation of volcanic ash in the atmosphere and its uncertainty is essential to perform accurate safety precautions. Currently, there exists no method for estimating the emissions of volcanic ash and its uncertainty for longer lasting eruptions, in which the eruption strength varies temporally in dependence on the emission height. This issue is adressed by the chemical part of the Ensemble for Stochastic Intergration of Atmospheric Simulations (ESIAS-chem) that comprises a particle smoother in combination with an ensemble-based discrete extension of the Nelder-Mead minimization method. The extended Nelder-Mead method is efficient in resolving the temporal and vertical distribution of the emissions in an ensemble environment. The particle smoother reduces the variance of the analysis ensemble in order to provide an accurate estimate of the emission profile. The system validation addresses the special challenge of ash cloud height analyses in case of observations restricted to bulk column mass loading information as is typical in the case of geostationary satellite data like thus obtained by SEVIRI. The ensemble version of the EURopean Air polution Dispersion - Inverse Model (EURAD-IM) is integrated into ESIAS-chem. Identical twin experiments identified the dependence of the system analysis on the wind conditions. Under strong wind conditions at the volcano, the temporal and vertical varying volcanic emissions are analyzed up to an error of only 10% by assimilating column mass loadings. For weak wind conditions, the analysis accuracy of the emission profile is limited, because the volcanic ash emitted at different times and heights is not sufficiently separated. In this case, only an enlongated assimilation window improves the analysis. The ability of ESIAS-chem to estimate real volcanic emissions is tested in a case study of the 2010 eruption of the Eyjafjallajökull volcano, Iceland.

3.1 KEYNOTE: All-sky assimilation of satellite radiances for global weather forecasting

Main Author: Alan Geer
Institution: ECMWF, Reading, UK

After much progress in forecast modelling, data assimilation, and in radiative transfer modelling, it is possible to assimilate satellite observations affected by cloud and precipitation. This brings new information in the most dynamically active regions of the atmosphere, and it helps correct errors in cloud and precipitation forecasts. At ECMWF around 20% of the constraint on the short-range operational forecast now comes from all-sky microwave radiances sensitive to humidity, cloud and precipitation. Important components in all-sky assimilation are (i) a radiative transfer model capable of simulating the scattering from cloud and precipitation particles; (ii) a data assimilation system capable of updating the initial conditions to correct errors in cloud and precipitation forecasts; and (iii) an observation error model that accounts for large representation errors in the presence of cloud and precipitation. Such an approach also relies on high-quality cloud and precipitation forecasts, meaning that systematic errors in the forecast model need special attention (see abstract by K. Lonitz). The operational use of all-sky microwave radiances is being improved in various areas, including better representation of scattering from frozen hydrometeors. Progress towards the assimilation of all-sky infrared radiances is continuing, but it is still hard to demonstrate benefits in operational forecasting. The framework that has worked so well for microwave observations needs further development to support infrared radiances. For example, the observation error model needs to represent inter-channel error correlations alongside the inflation of error variances in cloudy conditions. Also, a better treatment of cloud overlap is required in the observation operator. However, more fundamental issues are being revealed: all-sky infrared radiances do not just see cloud and water vapour, but also mesoscale features such as inertia-gravity waves and equatorial waves that are not yet properly handled in data assimilation systems.

3.2 Using solar satellite channels for convective-scale data assimilation

Main Author: Leonhard Scheck
Institution: LMU Munich / Hans-Ertel-Centre for Weather Research
Co-Authors: Bernhard Mayer, Martin Weissmann

High-resolution observations from instruments on geostationary satellites provide a wealth of information about convective activity and are therefore seen as a important type of observation for convective scale data assimilation (DA). In particular the solar channels provide information on the cloud distribution, cloud microphysical properties and cloud structure with high temporal and spatial resolution. However, in operational DA systems currently only clear sky thermal infrared and microwave radiance observations are used, which mainly provide temperature and humidity information. Sufficiently fast and accurate forward operators for visible and near-infrared radiances are not yet available, because multiple scattering makes radiative transfer (RT) at solar wavelengths complicated and computationally expensive.

Recently, we have developed a look-up table based 1D RT method that is orders of magnitude faster than conventional radiative transfer solvers for the visible spectrum and similarly accurate. The accuracy of the method has been increased further by means of fast approximations for 3D RT effects that are related to the inclination of cloud tops. A forward operator based on this RT method has been implemented to simulate synthetic MSG-SEVIRI images from COSMO-DE model output and is now integrated in the Km-scale Ensemble Data Assimilation (KENDA) system of DWD. We demonstrate that assimilating 0.6mu SEVIRI observations during strongly convective days in summer 2016 improves the cloud distribution in forecasts for several hours without degrading the beneficial impact of conventional observations significantly. Furthermore, we investigate the impact of varying important assimilation parameters like the superobbing length scale and the onservation error.

3.3 Towards improving the accuracy of low clouds and convective initiation in an LETKF

Main Author: Lilo Bach
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Co-Authors: Christoph Schraff, Christina Köpken-Watts, Ulrich Blahak, Leonhard Scheck, Roland Potthast

In the framework of the SINFONY (Seamless Integrated Forecasting System) project of Deutscher Wetterdienst, nowcasting and NWP methods are integrated to develop a seamless probabilistic prediction system for the convective scale. The targeted forecast horizon ranges from minutes to 12 hours. In addition to the integration of approaches and algorithms of the two usually separated areas, individual components of the future system are enhanced to develop an improved representation of heavy convective events. One key goal of SINFONY is the incorporation of further observational sources into the data assimilation system KENDA (Kilometre-scale ensemble data assimilation; Schraff et al., 2016) of DWD. So far, work on assimilating radar reflectivities and radial winds is carried out to improve the analysis in the presence of precipitation. However, to allow for accurate warnings ahead of convective precipitation and to approach the goal of a seamless transition from nowcasting to NWP, our objective is to improve the representation of convection already at the stage of its initiation. For that purpose, possibilities for the assimilation of cloud information derived from visible channels (SEVIRI-VIS) of geostationary satellites using the new fast and accurate observation operator MFASIS (Scheck et al. 2016) are explored. Visible channels are considered to have potential in the context of e.g. convective initiation and wintertime low stratus since they provide a more pronounced contrast of low clouds to the earth's surface than infrared channels. We present the methodology and results of different case studies using the convective-scale model COSMO-DE of DWD. Thereby we place special emphasis on the question of how to vertically position and localize the SEVIRI-VIS data representing a vertically integrated physical quantity.

3.4 Addressing biases in cloudy situations using the all-sky assimilation of microwave radiances

Main Author: Katrin Lonitz
Institution: Research Department, ECMWF, Reading, UK
Co-Authors: Alan Geer, Richard Forbes, Peter Bechtold

In an assimilation system, for most radiances bias correction is done only in clear-sky conditions. With the all-sky assimilation of microwave radiances it has become necessary to address biases in cloudy and precipitating conditions. At ECMWF, the first guess departures are normalised by the observation error in order to identify the most significant biases in the assimilation system. Different approaches can be used to account for biases in cloudy regions, for example in regions of stratocumulus clouds and cold-air outbreaks. The normal approach to correct for biases would be to use a linear bias correction model, but so far this has not often proved to be a viable way to correct for complex situation dependent cloud related biases. Instead, results suggest that it is better to exclude observations from the assimilation in some situations marked by cloud related biases, as for example in cold air outbreak regions. In these regions, the clouds are not well captured by most NWP and climate models. This leads to a shortwave radiation bias of about 0.2-0.4Wm-2 and a bias in the microwave of about 5-10K. The most optimal way to address this would be to improve the model to reduce or eliminate the bias. In fact, studying biases in the cold-air outbreak regions through the all-sky assimilation of microwave radiances has helped to identify the cause of this long-standing model error. In the latest cycle of the IFS important first steps have been taken to improve the representation of clouds in cold-air outbreak regions. In this study, we show the different approaches taken depending on the nature and impact of the cloud related bias. Furthermore, we demonstrate the potential to improve the representation of clouds inside the forecast model and the forward model by studying cloud related biases.

3.5 Assimilation of Himawari-8 All-Sky Radiances Every 10 Minutes: A Case of the September 2015 Kanto-Tohoku rainfall

Main Author: Takumi Honda
Institution: RIKEN AICS, Kobe, Japan
Co-Authors: Shunji Kotsuki, Guo-Yuan Lien, Yasumitsu Maejima, Kozo Okamoto, Takemasa Miyoshi

Severe rainfalls and their flood risk have attracted considerable attention from society because of their profound impacts including loss of life. To mitigate disasters associated with severe rainfalls, it is essential to obtain accurate precipitation forecasts in terms of intensity, location, and timing. To do so, data assimilation plays an essential role to provide better initial conditions. In particular, geostationary satellites are among the most important data sources because they can frequently observe a cloud system with broad coverage. In 2015, Japan Meteorological Agency (JMA) started full operations of a new generation satellite Himawari-8, which is capable of every-10-minute full disk observation and enables to refresh precipitation and flood predictions as frequently as every 10 minutes. This study aims to demonstrate the advantage of frequent updates of precipitation and flood risk predictions by assimilating all-sky Himawari-8 infrared (IR) radiances. We use an advanced regional data assimilation system known as the SCALE-LETKF, composed of a regional numerical weather prediction (NWP) model (SCALE-RM) and the Local Ensemble Transform Kalman Filter (LETKF). We focus on a major disaster case in Japan known as September 2015 Kanto-Tohoku heavy rainfall in which a meridional precipitation band associated with a tropical cyclone induced a record-breaking rainfall and eventually caused a collapse of a Kinu River levee. By assimilating a moisture sensitive IR band (band 9, 6.9 µm) of Himawari-8 every 10 minutes into a 6-km mesh SCALE-LETKF, the heavy precipitation forecasts are greatly improved. We run a rainfall-runoff model using the improved precipitation forecasts and predict flood risk with longer lead times.

Friday

7.5 KEYNOTE: On the scale- and case-dependence of the predictability of precipitation

Main Author: Madalina Surcel
Institution: Department of Atmospheric and Oceanic Sciences, McGill University, Canada
Co-Authors: Isztar Zawadzki, M. K. Yau

Given the high-dimensional phase space of atmospheric phenomena, atmospheric predictability is usually quantified in terms of the ability to predict a particular weather feature or weather variable. Even when only one particular weather variable is considered, its predictability is still found to be both scale- and case-dependent.

This talk presents lessons drawn from a study of the predictability of precipitation by storm-scale ensembles. Using a large data set of high-resolution ensemble precipitation forecasts over the Continental US, with different types of perturbation methodologies and mesoscale data assimilation, several questions are addressed. First, a methodology is presented that is used to characterize the scale dependence of the predictability of precipitation by an ensemble that accounts for both initial condition and model errors. The predictability by the ensemble is found to be very short-lived on average - 2 hours for scales smaller than 20 km and 10 hours for scales smaller than 200 km. Then, the case-dependence of precipitation predictability is also explored and the impact of different sources of forecast errors is assessed. While events characterized by large-scale forcing seem more predictable at large scales than diurnally forced events, small-scale predictability is always short-lived. Furthermore, statistical relationships between various event classifiers and predictability indices are found to be very weak. The results also show that all types of error sources considered in this study fail to explain the entire forecast error at small scales and for short forecast times, but that large-scale initial condition uncertainties are a major error source.

Finally, the gain in quantitative precipitation skill achieved through radar-data-assimilation, the advantage of sophisticated NWP models over simpler statistical forecasting methods for very-short term forecasting and the impacts of these findings for producing probability forecasts are also discussed.

7.6 Estimating the intrinsic limit of predictability using a stochastic convection scheme

Main Author: Tobias Selz
Institution: Meteorologisches Institut, LMU, München

Global model simulations together with a stochastic convection scheme are used to asses the intrinsic limit of predictability that originates from the convection up to planetary scales. The stochastic convection scheme has been shown to introduce an appropriate amount of variability onto the model grid without the need to resolve the convection explicitly. This greatly saves computational costs and enables a setup of twelve cases distributed over one year with 5 members generated by the stochastic convection scheme for each case. ECMWF forecasts are used to reflect current capabilities of forecasting and a direct comparison is performed to assess how much current weather prediction systems can be possibly improved. As a metric, difference kinetic energy at 300hPa over the midlatitudes, both north and south, is used. The resulting limit is estimated to be about 17 days when a threshold of 90% of the difference kinetic energy saturation level is applied. If the same threshold is applied to the ECMWF forecasts, the forecast limit is about 11 days, which results in a difference of six forecast days. This mean that e.g. a todays 8 day forecast can become a 14 day forecast in the future at best. These 6 days of potential improvement can be roughly divided into 3.5 days through perfecting the initial conditions and 2.5 days through perfecting the model.

7.7 Spread-Skill properties of the global ICON-EPS in comparison to the ECMWF-EPS and consequences for data assimilation

Main Author: Michael Denhard
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Since January 2018 DWD runs a global ICON Ensemble suite with 40 members and approx. 40km horizontal resolution with a grid refinement for Europe down to 20km. The forecasts start from analysis states generated by the Local Ensemble Transform Kalman Filter (LETKF) data assimilation (DA) system at DWD. Different sets of model parameter distinguish the ensemble members but no stochastic perturbations are added during the forecast. Therefore, the spread properties of the ICON-EPS are mainly determined by the variations in the analysis ensemble. The relation between spread and skill is perfect, if small spreads relate to situations of high predictability while large spreads are not useless. We show that the ICON-EPS and the ECMWF-EPS do not provide forecasts with a proper spread-skill relation in the short range when verifying against analysis fields. This confirms the results of Leutbecher and Palmer (2008) for the ECMWF-EPS, who found an improving spread skill relation during the forecast. In these systems the spread is not growing in the same way as the error. Hamill and Whitaker (2011) showed that balancing the perturbed states by using evolved perturbations helps in generating faster growing perturbations. We further argue that it is not only the balancing of model states or the amplitude of a perturbation what matters; it is the direction in state space which essentially determines the growth of perturbations. The assimilation steps of DA cycles may shift the background states to different places in the state space of the model with a possibly different tangent linear space and thus different error growth properties. Consequently, the background perturbations must be adapted to the new conditions to optimally explore the error growth potential.

3.6 Towards real-time assimilation of cloud

radar and lidar observations in the ECMWF 4D-Var System

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Co-Authors: Marta Janisková

Active observations from profiling instruments such as cloud radar or lidar contain a wealth of information on the vertical structure of clouds and precipitation. However, most NWP centres only assimilate observations of cloud with limited vertical information, such as radiances or near-surface rain rates. The immense detail provided by such active sensors, of great benefit to enhancing our understanding of clouds, paradoxically increases the difficulty in their use to initialize a forecast or generate a re-analysis, which we explore here. For example, any mis-match in the positioning of clouds between observation and model is difficult to reconcile. For radar, the forward model is extremely sensitive to assumptions on hydrometeor size. For lidar, any errors in the forward model can compound quickly where the signal is attenuated.

Characterising the observation errors correctly is particularly problematic, which tends to be highly situation-dependent. Diagnostic methods, which often rely on static observations errors, are likely to struggle. We therefore take an 'error inventory' approach, where we quantify the contribution from different sources of error. In particular, the narrow field-of-view of the instruments relative to the model scale means that the representativity error often dominates. We will demonstrate that, by treating this as a sampling error, we can use the local variance of the measurement to provide a flow-dependent estimate of the representativity error. The method also predicts the correlations in representativity error, which can be large in the vertical. The error from uncertainties in the forward models are also accounted for, using a Monte Carlo approach where parameters are perturbed within physical bounds. Crucial practical elements, such as bias correction and screening of observations will also be discussed.

The upcoming EarthCARE mission, due for launch in 2019, offers a unique opportunity to exploit these new observations and assess their benefit for NWP.

3.7 Ensemble-Based Data Assimilation of GPM/DPR Reflectivity into the Nonhydrostatic Icosahedral Atmospheric Model NICAM

Main Author: Shunji Kotsuki
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Co-Authors: Koji Terasaki, Takemasa Miyoshi

This study aims to improve the precipitation forecasts from numerical weather prediction models through effective assimilation of satellite-observed precipitation data. The assimilation of precipitation data is known to be difficult mainly due to highly non-Gaussian statistics of precipitation-related variables involved with complicated cloud processes such as water phase changes. We have been developing a global atmospheric data assimilation system NICAM-LETKF, which comprises the Nonhydrostatic ICosahedral Atmospheric Model (NICAM) and Local Ensemble Transform Kalman Filter (LETKF). Using the NICAM-LETKF system, Kotsuki et al. (2017, JGR) successfully improved the weather forecasts by assimilating the Japan Aerospace eXploration Agency (JAXA)'s Global Satellite Mapping of Precipitation (GSMaP) data into the NICAM at 112-km horizontal resolution. However, assimilating space-borne precipitation radar data remains to be a challenging issue. This study pioneers to assimilate radar reflectivity measured by the Dual-frequency Precipitation Radar (DPR) onboard the Global Precipitation Measurement (GPM) core satellite into the NICAM. We conduct the NICAM-LETKF experiments at 28-km horizontal resolution with explicit cloud microphysics of a single-moment 6-class bulk microphysics scheme. To simulate GPM/DPR reflectivity from NICAM model outputs, the joint-simulator (Hashino et al. 2013; JGR) is used. Our initial tests were promising, showing a better match with the observed reflectivity by assimilating GPM/DPR reflectivity into NICAM forecasts. This presentation will include the most recent progress up to the time of the symposium.

3.8 Nonlinear Bias Correction for Satellite Data Assimilation using A Taylor Series Polynomial Expansion of the Observation Departures

Main Author: Jason Otkin
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Co-Authors: Roland Potthast, Amos Lawless

Output from a high-resolution ensemble data assimilation system is used to assess the ability of a nonlinear bias correction (NBC) method that uses a Taylor series polynomial expansion of the observation-minus-background departures to remove linear and nonlinear conditional biases from all-sky satellite infrared brightness temperatures. Univariate and multivariate NBC experiments were performed in which the satellite zenith angle and variables sensitive to clouds and water vapor were used as the bias correction predictors. The results showed that even though the bias of the entire error distribution is equal to zero regardless of the order of the Taylor series expansion, that there are often large conditional biases that vary as a nonlinear function of the predictor value. The linear 1st order Taylor series term had the largest impact on the entire distribution as measured by reductions in the variance; however, large conditional biases often remained across the distribution when plotted as a function of the predictor. These conditional biases were typically reduced to near zero when the nonlinear 2nd and 3rd order terms were used. The univariate results showed that variables sensitive to the cloud top height are effective NBC predictors especially when higher order Taylor series terms are used. Comparison of statistics for clear-sky and cloudy-sky matched observations revealed that nonlinear bias corrections are more important for cloudy-sky observations as signified by the much larger impact of the 2nd (quadratic) and 3rd (cubic) order terms on the conditional biases. Together, these results indicate that the NBC method is an effective method to remove the bias from all-sky satellite infrared brightness temperatures.

4.11 Episodic, non-linear and non-Gaussian: ensemble data assimilation for bounded semi-positive definite variables like cloud.

Main Author: Craig Bishop
Institution: Naval Research Laboratory

The uncertainty distributions of forecasts of episodic variables such as clouds, precipitation, fire and ice often feature a finite probability of non-existence and/or skewness. For such variables, existing data assimilation techniques such as 4DVAR, the Ensemble Kalman Filter (EnKF) and the Particle Filter (PF) fail when a finite amount of the variable is observed but the prior forecast uncertainty distribution assigns a probability density of zero to this observation. Here we extend the previously developed Gamma, Inverse-Gamma and Gaussian (GIGG) variation on the EnKF to accommodate finite probabilities of non-existence. The resulting GIGG-Delta filter has the remarkable property that when rain (for example) is observed, the GIGG-Delta filter always produces a posterior ensemble of raining ensemble members even if not one of the prior forecast ensemble members contain rain. In addition, the GIGG-Delta filter accurately solves Bayes' theorem when the prior and observational uncertainties are given by gamma and inverse-gamma pdfs, respectively. To improve the multi-variate dynamical balance of the posterior distributions, a new iterative balancing procedure is proposed that improves the ability of the EnKF to produce balanced posterior states. The approach is tested, illustrated and compared with existing techniques using a hierarchy of idealized models.

4.12 Toward improved LETKF assimilation of non-local and dense observation by direct covariance localization in model space

Main Author: Daisuke Hotta
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Covariance localization is an indispensable component of ensemble-based data assimilation systems with a limited member size. The benefit of localization is two-fold: (1) it suppresses spurious correlation due to sampling error, and (2) mitigates the rank-deficiency issue of the sample covariance matrix.

In Local Ensemble Transform Kalman Filter (LETKF), localization is typically implemented by domain localization (i.e., by performing analysis independently at each model grid) and by applying the so-called R-localization, in which the impact of an observation to the analyzed state variable is artificially damped by inflating the observation error variance by a factor that is a decreasing function of the physical distance between the observation and the analyzed grid.

Recent study at Japan Meteorological Agency using its operational global LETKF revealed that, while R-localization effectively suppresses spurious impact from an observation onto remote grids, it does not help to alleviate the rank deficiency issue within the local analysis, hindering the LETKF from extracting information from dense observations. R-localization also poses difficulty when assimilating non-local observations (e.g., ground-based GNSS observations, satellite radiances, or even in-situ surface pressure observations) whose physical locations are not clearly defined.

To resolve the above issues, we explore possibility of applying model-space localization within the framework of LETKF. The advantage of model-space localization over the R-localization will be discussed using an idealized one-dimensional toy system. The toy system is designed with assimilation of ground-based GNSS observations mind, but the methodology should also work for other non-local and dense observation types such as satellite radiances.

4.13 Developments in the ECMWF humidity background errors

Main Author: Elias Holm
Institution: European Centre for Medium-Range Weather Forecasts

The background error used in 4D-Var and the EDA has unbalanced relative humidity as control variable, with analytic balance operator between humidity and temperature in cloudy conditions. Recent developments have added humidity background error variances taken directly from the Ensemble of Data Assimilations (EDA), like for all other variables. This replaces earlier background and level dependent statistical estimates of the humidity variances. This change improved forecast scores and background fit to observations, including winds, and went operational 11 July 2017. We will show some selected results from this change and discuss some further developments with a new analytic balance operator coupling humidity and dynamic background errors.