Abstracts Poster

1 Erdem Altuntac

Reconstruction of the atmospheric state by remote sensing technology

As a method of remote sensing, GPS-tomography technology is considered to understand the atmospheric state. This technology is widely used for umerical weather prediction systems by many weather services in the world.As an inverse problem, the task here is the reconstruction of refractivity profile, i.e. optical density, of the humidity field from some noisy tomographic measurement. This measurement type is classified as time-of-flight type data since it is calculating the time elapsing while signals between stations and satellites pass through the atmosphere. One vital point must be emphasized here before proceeding; Those signals are delayed since they follow another path by bending while traversing the atmosphere. The bending is observed especially when the signals enter troposphere layer. The main assumption of this work is that the signals do not encounter any bending. These signals are then some straight lines connecting the stations to the GPS satellites, and there are points defining the optical density of the humidity field through those lines. Forward operator operates on those points to obtain the positive valued measurements. Thus our problem turns out to be finding the density of some layer of the atmosphere defined on the three-dimensional real space from those measurements. From this perspective, this tomography problem is an application of fan-beam tomography.
Speaking more about the measurement procedure, this procedure is an engineering realization of Fermat's principle, or principle of least time, in optics. It is the principle that a ray of light taken between any pair of points is the path that can be traversed in the least time. Within this period of time electromagnetic waves must cover a path throught out the signal.
For the sake of convenience, target function which is to be reconstructed from set of line integrations is considered to be the density function of some three-dimensional medium. First part of this work focuses on minimizing some total variation type cost functional which includes noisy measurement. As a computationally economic method, lagged diffusivity type algorithm is studied to minimize this type of cost functional. Behaviour of the solution and some heuristic regularization parameter have the advantage of the regularization term's convexity. Deterministic numerical analysis is carried out during the study. While analysing the behaviour of the reconstruction, we will also see a deep connection between Tikhonov regularization and the lagged diffusivity fixed point iteration.
In the second part, we focus on retrieval theory arising in data assimilation. This theory is to deal with assimilation the two types of data. Connecting this theory to GPS-tomography problem, we assume that some retrieved data is calculated from the measurement data. This calculation in fact is the early solution to some minimization problem like above in the first part. In our case this solution is the information about the humidity field. By the retrieval theory we consider this information tune into data assimilation systems together with some other type of data, i.e. radiances.

2 Javier Amezcua

On Gaussian anamorphosis

Using the ensemble Kalman filter is optimal when (a) the prior distribution of the state variables is Gaussian, (b) the distribution of the observational error is Gaussian, and (c) observations are a linear transformation of the state variables combined with an additive observation error term. Suboptimal yet useful results can be obtained when the EnKF is applied despite violating these conditions. If these violations are large, its performance can be compromised.
When (a) is largely violated, a pre-processing step known as Gaussian anamorphosis is often applied: mapping the state variable into a Gaussian variable. The EnKF is applied in the transformed variable, and the resulting analysis value is mapped back. Here we analyse a more general case: violating (a) and (b). Using this case as motivation allows us to define Gaussian anamorphosis as a general bivariate transformation. Moreover, we show that this process is not unique, that existing transformations can be englobed under the bivariate framework. Different transformations will achieve different objectives -i.e. marginal Gaussianity for the prior and/or likelihood-, and they also bring associated problems -i.e. the introduction of nonlinear observation operators in the transformed space-. We suggest a bivariate transformation that achieves bivariate Gaussian distribution for the pair {transformed state variables, transformed observations}, and show that it has special value when the likelihood is non-Gaussian.
A key point is that, when (a)-(c) are violated, using the EnKF will not recover the exact posterior density inspite of any transformations one may perform. These transformations, howover, provide approximate answers of different quality. We analyse these different choices.

Coauthors: Peter Jan van Leeuwen

3 Liselotte Bach

Selfbreeding - a new approach for estimating uncertainty structures in limited-area models

Assessing uncertainty using ensemble methods becomes more and more important in meso-scale NWP. Most methods utilize perturbed model physics and/or different boundary conditions to generate multiple forecast realizations. We propose an initialization technique that particularly meets the spatiotemporal characteristics for meso-scale NWP.
The so-called selfbreeding technique is based on the breeding of growing modes technique thus making use of the full nonlinear model in a cyclical process in order to generate dynamically constrained perturbations. While classical breeding is a continuous cycling in time we apply the forecasting-rescaling process to the same time interval thus allowing the system to identify the optimal growing error modes for this period similar to the Singular Vector method but without the need for a tangent linear or adjoint model. Our implementation also enables the user to target uncertainties of specific mesoscale processes, e.g. convective instability.
Experiments show that the error growth saturates after a reasonable number of selfbreeding cycles thus indicating mature perturbations consistent with the systems`s dynamics. These could be used to initialize a meso-scale ensemble.
We present results from a case study experiment for a regime of convective instability in a subdomain of the limited-area model COSMO-EU. These include properties of the estimated uncertainty structures, the dimensionality of the set of perturbations as well as an extension of the selfbreeding technique with an Ensemble Transform algorithm.

Coauthors: Jan D.Keller, Andreas Hense

4 Christoph Bergemann

Particle filter based data assimilation into an air quality model

We demonstrate the use of a Bayesian filter for data assimilation into a regional air quality model. In this study, we apply the filtering system to a model ensemble based on the POLYPHEMUS/DLR air quality model over the Alpine area. Since the uncertainty in air quality models is in a large part determined by the uncertainty in the driving parameters (e.g. emissions and meteorology), the ensemble is generated by modification of these parameters. We discuss how this fact needs to be reflected in the application of Bayes' equation. In this way we are able to improve the performance statistics of the analysis for the trace gases NO2 and O3.

5 Theresa Bick

Assimilation of radar reflectivity measurements in COSMO-DE using the LETKF

The prediction of convective events is a difficult task due to the nonlinear and chaotic behavior of the atmosphere on this scale. Therefore, data assimilation is crucial to enhance numerical weather prediction. Radar observations represent an ideal data base due to their capability to capture the 3D spatial and temporal evolution of convective systems. However, the assimilation of radar data is not straightforward, because reflectivity is not a prognostic model variable. Thus, the radar forward operator developed at the Karlsruhe Institute of Technology and the German Weather Service (DWD) is applied in order to derive synthetic radar volume scans based on the COSMO-DE model output. The obtained pseudo-reflectivities enable the comparison of the model forecast with the actual observation.
Ensemble Kalman Filters are able to directly gain information from this comparison in the observation space. Related to linear regression, they transfer the information back onto the model states.
Within the DWD project KENDA (Km-scale Ensemble-based data assimilation), a Local Ensemble Transform Kalman Filter (LETKF) is currently under development. This LETKF setup, combined with the radar forward operator, is used to assimilate reflectivity measurements from the DWD C-band radar network into COSMO-DE. First results based on case studies will be presented.

Coauthors: Silke Trömel, Kathrin Wapler, Clemens Simmer

6 Yuan Cheng

The Ensemble Transform Particle Filter and Localization

The ensemble Kalman Filter (EnKF) with all its different variants can be considered the state-of-the-art way to perform data assimilation, despite the fact that in non-linear systems it does not converge to the exact solution. The theoretically better particle filters have not found their way into applications that deal with high dimensional systems. This is largely due to the fact that in practice the number of ensemble members or particles is limited and the concept of localization, which can be seen as a way of dimensionality reduction, has been successfully applied to the EnKF. For particle filters it is still an open question of how to localize. We introduce a novel filter which transforms the particles based on the solution of an optimal transport problem allowing us to incorporate information on the spatial structure of the state space. Numerical results show that this method can compete with the EnKF even for very small ensemble sizes and, as expected, outperforms it for large ones.

Coauthors: Sebastian Reich

7 Nawinda Chutsagulprom

Ensemble Transform Filters based on Gaussian Mixture Density

The ensemble Kalman filter (EnKF) and sequential importance resampling (SIR) are generic data assimilation techniques that have been developed to estimate states of physically-based nonlinear systems. Both methods have their intrinsic drawbacks: the EnKF can be limited by its inherent Gaussian assumption, whereas SIR may require a large number of particles to capture the high probability region of the posterior in high-dimensional applications.
In this work, novel approaches to nonlinear/non-Gaussian Bayesian state estimation are introduced. These are extensions of the Rank Histogram Filter (RHF) proposed by Anderson (2010). First, instead of modelling the prior observation distribution by using the rank histogram concept, a nonparametric Gaussian mixture is employed. Second, we further investigate the updates of unobserved states based on the idea of deterministic coupling (Reich and Cotter, 2012) instead of using the standard linear regression approach.
Numerical experiments are performed on different dynamical scenarios and show the potential to provide better results with nonlinearity and non-Gaussianity for a small number of ensembles, compared with the standard EnKF and RHF.

Coauthors: Sebastian Reich

8 Yovany Cordero Hernandez

Covariance update in data assimilation for parameters and state estimation

The goal of data assimilation is to estimate the true state of a dynamical system with the aid of numerical methods, taking into account observations (measurements), a forecast model, the initial state and statistical information of observations, model and forecast errors. Data assimilation is also crucial for adapting mathematical models, which are defective or inaccurate and contain uncertain or unknown data. A usual approach for cases where models depend on poorly known parameters is to solve both problems (data assimilation and parameter estimation) at the same time with an augmented state approach, considering the parameters as variables in a modified data assimilation problem. In this work we investigate the influence of the covariance on the data assimilation on state and parameter estimation problem. We propose a forward update of the state covariance matrix, which is less expensive than the classical Extended Kalman Filter (ETKF) method. It uses the information of the parameter-state cross covariance matrix and does not require the application of the nonlinear forward operator to the high dimensional state covariance. The suitability of the proposed strategy is demonstrated on several numerical experiments.

Coauthors: Angelika Bunse-Gerstner

9 Sarah Dance

Incorporating Correlated Observation Errors in Ensemble Data Assimilation

Observation errors are not properly accounted for in data assimilation schemes. In this work we develop a new method for diagnosing and incorporating correlated and time-dependent forward model error in an ensemble data assimilation system. The method combines an ensemble transform Kalman filter with a method proposed by Desroziers et al. that uses statistical averages of background and analysis innovations to provide an estimate of the observation error covariance matrix. From this estimate of the observation error covariance matrix the uncorrelated instrument error can be subtracted to provide an online estimate of the time dependent forward model error covariance. To evaluate the performance of the method we run identical twin experiments in a simplified model. Using this approach we are able to recover the true observation error covariance in cases where the initial estimate of the error covariance is incorrect, and follow time-varying observation error covariances where the length-scale of the true covariance is changing slowly in time. We find also that including the estimated forward model error in the assimilation improves the analysis. More recent work has applied a similar technique to diagnose observation errors for Doppler radar winds in the Met Office UK model.

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10 Le Duc

Covariance localization in the approximated Karhunen-Loève basis

The ensemble Kalman filter estimates the forecast covariance matrices from a finite realization of the system state. It can be proved that the estimated errors of off-diagonal terms of a covariance matrix depend on the diagonal terms (variances). This dependence of estimated errors of off-diagonal terms on variances is known as the sampling errors and localization is used to remove such spurious correlations. Here, we prove that if localization is employed in the basis that diagonalizes the covariance matrix (Karhunen-Loève basis) instead of the standard one, the estimated errors will reduce.
However in practice the true covariance is unknown and so its Karhunen-Loève basis is. Considering only the bases in which the covariance matrix has negligible off-diagonal terms, the Karhunen-Loève basis can be approximated with the basis that maximizes the sum of squared variances. We can select the best approximated Karhunen-Loève basis among a dictionary of bases like wavelets and local cosines. The test in one-dimensional case with the Kuramoto-Sivashinsky equation will be shown.

Coauthors: Kazuo Saito

11 Le Duc

Data assimilation experiments of Myanmar cyclone Nargis based on NHM-LETKF

Data assimilation experiments on Myanmar tropical cyclone (TC) Nargis using Local Ensemble Transform Kalman Filter (LETKF) method and NHM model were performed to examine the impact of LETKF on analysis performance in real cases with sparse observations. NHM is the operational non-hydrostatic meso-scale model of Japan Meteorological Agency. The subsequent forecast based on the original NHM-LETKF analysis showed a good forecast in track and intensity compared to the direct downscaling from the global model of JMA. However the ensemble mean track had a small southward displacement and both deterministic and ensemble mean forecasts underestimated the peak of intensities.
Some strategies to further improve the final analysis were considered. They are SST perturbations, assimilation of TC advisories, and Running in Place (RIP). SST perturbations were derived from SST analyses from operational centers. Assimilation of TC advisories requires an implementation of a new observation operator in NHM-LETKF. RIP is equivalent to iterating LETKF several times at assimilation phases. The use of SST perturbations slightly improves the Nargis track and intensity forecast. Assimilation of TC advisories and RIP can have a positive impact with a reasonable choice of their free parameters. The overconfidence on estimated intensities in assimilation of TC advisories or the overuse of observations in RIP can strengthen Nargis considerably. However the subsequent track forecasts exhibited northward displacements.

Coauthors: Tohru Kuroda, Kazuo Saito, Tadashi Fujita

12 Jonathan Flowerdew

Towards a theory of optimal localisation

Practical ensemble-based atmospheric data assimilation systems ubiquitously apply localisation to reduce the damaging impact of spurious long-range correlations arising from the finite ensemble size. However, the form of the localisation function is generally fixed, ad-hoc, and requires expensive tuning to optimise the system. For the case of a single observation and known true background error correlation, it is possible to derive an optimal localisation factor that minimises the expected root-mean square (RMS) analysis error. Idealised tests show this process to be effective for all but the highest observation densities, where a more elaborate theory is required. The formulation has a number of interesting consequences. The width of the implied localisation function varies with the width of the underlying correlation, but does not have the same shape. The expected RMS error can be calculated and is larger than that for a perfect data assimilation system: this implies that stochastic ensemble filters may have an advantage over deterministic filters, which assume the RMS error for perfect assimilation. Superior performance may be obtained by damping sample correlations towards a climatologically-estimated correlation, rather than zero. The nonlinear mapping from correlation to localisation suggests a new approach to vertically-integrating observations, where localisation based on the expected observation-space correlations may even be superior to model-space localisation.

13 Kathrin Folger

Height correction of AMVs using satellite lidar observations from CALIPSO

Uncertainties in the height assignment of Atmospheric Motion Vectors (AMVs) are the main contributor to the total AMV wind error. These uncertainties introduce errors that can be horizontally correlated over several hundred kilometres, which poses a severe issue for their assimilation in NWP models. For this reason, we investigate how to improve the AMV pressure heights for Meteosat-9- and Meteosat-10-AMVs, firstly with independent satellite lidar observations from CALIPSO, and secondly by treating AMVs as layer-winds instead of winds at a discrete level. The wind verification is done with operational radiosondes during an 8 month period in 2012/2013. The satellite lidar-AMV height correction reveals that the wind error of AMVs can be reduced by 12-17% when AMV winds are assigned to 120 hPa deep layers below the cloud tops derived from nearby lidar observations [1].
In addition, the lidar-AMV height correction is expected to reduce the correlation of AMV errors as lidars provide high-resolution cloud top observations that are expected to be independent of the height assignment method used in the AMV processing.
Further studies are planned to investigate the benefit of assimilating lidar-corrected AMVs in NWP models and the potential of deriving situation-dependent correction functions for AMV heights based on lidar information.

Coauthors: Martin Weissmann

14 Gernot Geppert

Estimating canopy albedo parameters: Insights from experiments with double-bounded, non-Gaussian variables and the ensemble Kalman filter

Earth system models simulate land surface albedo in a simplified manner as the weighted average of background albedo and canopy albedo. Their weights are derived from the leaf area index and background albedo and canopy albedo are fixed parameters. Inversions of land surface albedo observations, however, indicate a seasonal cycle of canopy albedo.
To estimate a time series of canopy albedo parameters, we set up a sequential data assimilation framework based on the Data Assimilation Research Testbed (DART) and the land component of the MPI Earth System Model. We use the ensemble Kalman filter (EnKF) to update the parameters every time a new observation is available. Because the EnKF is optimal only for Gaussian distributions and does not constrain estimates to their physical boundaries, we extended DART with Gaussian anamorphosis. This technique transforms the states and the observations in conjunction with their error covariances from (0, 1) to (??, ?) and yields probability distributions that are closer to Gaussian distributions.
We performed experiments with synthetic observations of visible and near-infrared surface albedo. We successfully tested the framework for consistency (perfect initial conditions are not deteriorated) and for the retrieval of fixed and seasonal parameters from perfect observations as well as from albedo observations with errors of the order of 0.01 [-]. In the latter case, additive inflation in the untransformed space is necessary. For larger errors of the order of 0.04, an unwanted weighting effect due to the non-linear transformation leads to a bias in the retrieved parameters.

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15 Michael Goodliff

A Comparison of Different Hybrid Methods on the Lorenz 1963 Model

Hybrid data assimilation schemes are becoming more widely used in Numerical Weather Prediction (NWP). These methods combine ideas from successful schemes such as 4DVAR and the ensemble transform Kalman filter (ETKF). The motivation behind hybrid schemes is to make use of a flow-dependent background error covariance matrix (Pb) in a variational setting.
Although some of these hybrid schemes are being used operationally now, several basic questions on the reasons behind their performance are still open.
Hybrid methods mainly differ in their use of Pb. Here we study 3 formulations. The first scheme, ETKF-4DVAR, uses Pb from the ETKF and combines it (weighted) with the climatological background error covariance matrix in 4DVAR (Bclim), at the start of each assimilation window. The second scheme, 4DVAR-BEN, is similar to ETKF-4DVAR but has zero weighting on Bclim. The third scheme, 4DENVAR, uses a the 4-dimensional covariance from the ensemble that alleviates the need for the tangent-linear and adjoint model in the 4DVar.
We systematically compare the performance of ETKF-4DVAR, 4DVAR-BEN and 4DENVAR with respect to two traditional schemes (4DVAR and ETKF) on the Lorenz 1963 model. Using the analysis root mean square error (RMSE) as a metric, these schemes have been compared considering (1) assimilation window length and observation interval size, (2) ensemble size and (3) inflation of the climatological background error covariance matrix.

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16 Mylene Haslehner

Testing particle filters on convective scale dynamics

Particle filters have been developed in recent years to deal with highly nonlinear dynamics and non Gaussian error statistics that also characterize data assimilation on convective scales. In this work we explore the use of efficient particle filter (P.v. Leeuwen, 2011) for convective scale data assimilation application. The method is tested in idealized setting, on two stochastic models. The models were designed to reproduce some of the properties of convection, for example the rapid development and decay of convective clouds.
The first model is a simple one-dimensional, discrete state birth-death model of clouds (Craig and Würsch, 2012). For this model, the efficient particle filter that includes nudging the variables shows significant improvement compared to Ensemble Kalman Filter and Sequential Importance Resampling (SIR) particle filter. The success of the combination of nudging and resampling, measured as RMS error with respect to the 'true state', is proportional to the nudging intensity. Significantly, even a very weak nudging intensity brings notable improvement over SIR.
The second model is a modified version of a stochastic shallow water model (Würsch and Craig 2013), which contains more realistic dynamical characteristics of convective scale phenomena. Using the efficient particle filter and different combination of observations of the three field variables (wind, water 'height' and rain) allows the particle filter to be evaluated in comparison to a regime where only nudging is used. Sensitivity to the properties of the model error covariance is also considered. Finally, criteria are identified under which the efficient particle filter outperforms nudging alone.

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17 Tijana Janjic

Application of mass and positivity constraint for radar data assimilation with a localized ensemble transform Kalman filter

Data assimilation on convective scales needs to capture fast changing processes and many scales of motion that are resolved in high resolution models. Therefore, it is beneficial for the data assimilation algorithm to have time evolving error covariances as represented through an ensemble. Results from previous studies show that Ensemble Kalman Filter (EnKF) techniques can be applied for the convective scale data assimilation, in both real data experiments (Dowell et al. 2004) as well as in observing system simulation experiments (e.g. Snyder and Zhang 2003; Zhang et al. 2004). Observations such as radar reflectivity or cloud products are important for prediction on these scales, but difficult to assimilate with the EnKF due to background errors which are non-Gaussian in nature. To deal with the non-Gaussianity in an EnKF framework, we propose the use of physically based constraints in the analysis step to weakly constrain the solution and therefore change the analysis error statistics.

We suggest modifications to the localized ensemble transform Kalman filter (LETKF) in order to approximately preserve two a priori chosen physical properties of positivity and total mass. The benefit on prediction is illustrated in an idealized setup (Lange and Craig, 2013). This setup uses the non-hydrostatic COSMO model with a 2 km horizontal resolution, and the LETKF as implemented in KENDA (Km-scale Ensemble Data Assimilation) system of German Weather Service (Reich et al. 2011). Random perturbations of temperature and vertical wind in statically unstable conditions initiate convective systems with lifetimes over six hours. Simulated observations of radar data are drawn from a true run and are assimilated with the LETKF in order to analyze the location and intensity of the storms in the ensemble members. Due to the Gaussian assumptions that underline the LETKF algorithm, the analyses of water species will become negative in some grid points of the COSMO model. These values are set to zero currently in KENDA after the LETKF analysis step, in order not to give the numerical model unphysical values. The tests done within this setup show that such a procedure introduces a wet bias in the analysis ensemble with respect to the true, that increases in time due to the cycled data assimilation. As will be shown, weak constraints on mass and positivity alleviate the problem.

Coauthors: Heiner Lange

18 Tijana Janjic

Mass Conservation and Positivity Preservation with Ensemble-type Kalman Filter Algorithms

Maintaining conservative physical laws numerically has long been recognized as being important in the development of numerical weather prediction (NWP) models. In the broader context of data assimilation, concerted efforts to maintain conservation laws numerically and to understand the significance of doing so have begun only recently.

We incorporate constraints to enforce physically based conservation laws in the ensemble Kalman filter. In particular, constraints are used to ensure that the filter ensemble members and the ensemble mean conserve mass and remain nonnegative through measurement updates. We show that the analysis steps of ensemble transform Kalman filter (ETKF) algorithm and ensemble Kalman filter algorithm (EnKF) can conserve the mass integral, but do not preserve positivity. Further, if localization is applied or if negative values are simply set to zero, then the total mass is not conserved either. In order to ensure mass conservation, a projection matrix that corrects for localization effects is constructed. In order to maintain both mass conservation and positivity preservation through the analysis step, we construct a data assimilation algorithms based on quadratic programming and ensemble Kalman filtering.

Mass and positivity are both preserved by formulating the filter update as a set of quadratic programming problems that incorporate constraints. Some simple numerical experiments indicate that this approach can have a significant positive impact on the posterior ensemble distribution, giving results that are more physically plausible both for individual ensemble members and for the ensemble mean. The results show clear improvements in both analyses and forecasts, particularly in the presence of localized features.

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19 Ivan Kasanicky

Spectral Diagonal Covariance in Ensemble Kalman Filters

Several variants of Ensemble Kalman filter (EnKF) based on Fast Fourier transform (FFT) or Discrete Wavelet transform (DWT) have been proposed recently. The main idea of these methods is to estimate the true forecast covariance matrix using only diagonal elements of sample covariance in spectral space, which reduces the amount of computations required by the EnKF, as well as the necessary ensemble size. This approach is inspired by the fact that diagonal form of covariance implies, that the underlying random field is stationary for infinite dimensional grid and close to stationary for the finite domain. In the proposed contribution we will examine the proper conditions, under which the true covariance is diagonal. We also show relationship between stationarity of underlying random field and the form of true covariance in spectral space. The analytical form of error of spectral diagonal covariance approximation, as a function of ensemble size, will be also derived. Simulations have shown, that theoretical values of expected errors are obtained even for very low ensemble sizes. In the last part of the contribution we will show that the error does not excessively rise even if the assumed conditions for spectral covariance are not completely fulfilled and a comparison between standard EnKF and spectral EnKF (FFT and DWT) will be presented.

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20 Tom Kent

A modified rotating shallow water system for testing convective-scale data assimilation

Data assimilation techniques need to evolve in order to keep up with the developments in convection-permitting Numerical Weather Prediction models. It is often unfeasible, and indeed undesirable, to investigate the potential of new data assimilation schemes on operational forecasting systems. Instead, idealised models are employed that capture the fundamental features of convective-scale dynamics while remaining computationally inexpensive, thus allowing for an extensive investigation of the proposed scheme.
Here, we outline an augmented rotating shallow water system to model an idealised atmosphere with moist convection. Moisture is represented by a 'rain mass fraction' which acts on the momentum equation via the geopotential, and is allowed to precipitate via an additional conservation equation. By combining the non-linearity due to the onset of precipitation and the genuine hydrodynamic non-linearity of the shallow water equations, the proposed model captures the fundamental dynamical processes of convecting and precipitating weather systems.
The system is a valid non-conservative hyperbolic system of partial differential equations and can thus be solved numerically using a shock-capturing finite volume/element framework which deals robustly with the high non-linearity and so-called non-conservative products. The model produces synthetic observations for investigating an ensemble Kalman filter data assimilation scheme.

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21 Paul Kirchgessner

A comparison of linear and non-linear linear data assimilation techniques using a toy model

Current state-of-the art data assimilation methods rely on linearity assumptions, which are not valid in general. Moreover increasing the resolution of the current models also introduces more and more non-linearity. Recently the equivalent weights particle filter (EWPF, Van Leeuwen 2009), a non-linear data assimilation method, were developed to deal with both of these problems.
First results using these methods show promising results for state estimation in data assimilation (see Ades 2012, Van Leeuwen 2010). But still, a clear understanding of the difference and improvements compared to the currently used EnKF methods is lacking.
To gain a better understanding of the differences, we perform a set of twin experiments with the Lorenz-96 model and compare the analysis results of the EWPF to the currently used ESTKF (Nerger et al. 2011).
We discuss the performance of both methods using classical metrics, as well as new metrics appropriate for non-linear data assimilation problems.

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22 Andrea Klus

Adaptive error subspace methods for ensemble based Kalman filters

The idea of resampling is applied to the Ensemble Transform Kalman filter (ETKF) with domain localization. It already has been used to improve the Singular Evolutive Extended Kalman filter (SEEK). Based on the Lorenz-96 model it is tested for several variants of the observation operator whether the use of resampling is helpful in the localized ETKF or not.
After each assimilation step the ensemble member that offers the least information to the error subspace is replaced by a new created ensemble member. Different approaches are made to create this new member. The first idea is to use the residuum, so the difference between the analysis and the observation at that time step. The other idea is to weight the analysis and the observation with the Kalman matrix to get an improved analysis. The hope is that the new ensemble error that belongs to the new ensemble member is enriching the error subspace with a suitable direction. Experiments are made with the Lorenz-96 model and the Parallel Data Assimilation Framework (PDAF, http:pdaf.awi.de).

23 Tohru Kuroda

Four Dimensional LETKF Analysis with Dual Resolution on a Heavy Rain Case in Kyushu, Japan

Local Ensemble Transform Kalman Filter (LETKF) is one of promising analysis schemes,?which shows high scalability on parallel computers. By adopting techniques such as localization, inflation or 4 dimensional (4D) method, LETKF can execute analysis with a high resolution and with a reasonable computational cost. Based on Miyoshi and Aranami (2006), Fujita (2011) developed a 4D-LETKF system with no-cost Ensemble Kalman smoother employing the JMA Non-Hydrostatic model (NHM) as the forecast model. After the calculation of 4D-LETKF in which horizontal and vertical localizations and adaptive inflation are implemented, the smoother is executed. Difference between the smoother analysis and control guess forecasts gives analysis increment. In one analysis cycle, a 4D method uses several time slots and a time of an observation is rounded to the nearest slot. After some cycles, we obtain the analysis field at the target time. This implementation can evolve to a dual resolution (DR) analysis system in which a low resolution for the ensemble forecast and a high resolution for the control guess forecast and the smoother are used. Use of the low resolution contributes to saving the computational cost and employing large ensemble size. Use of the high resolution for the smoother yields detailed structure of the analysis increment. Using DR 4D-LETKF, we can expect more improved analysis than that with fully low resolution.
We conducted a case study on local heavy rain occurred in Kyushu, Western Japan. We show that the high resolution analysis brought by DR 4D-LETKF gives more realistic rain fall intensity.

Coauthors: Tadashi Fujita, Hiromu Seko, Kazuo Saito

24 Matthew Lang

Improving model parameterisations through Data Assimilation

In Numerical Weather Prediction (NWP), parameterisations are used to compensate for errors in the model. Errors in NWP models can be due to a lack of scientific understanding or a lack of computing power available to address all known physical processes. Parameterisations are sources of large uncertainty in a model as parameter values used in them are often not well known and/or unmeasurable quantities.
Whilst there are many efficient and effective methods for state/parameter estimation in data assimilation, there are few methods for estimating parameters that can be extended to the estimation of parameterisations. This is due to the fact that in order to estimate parameterisations, we also need to deduce the structure of the model errors. The method we propose has the potential to utilise these structures and hence estimate parameterisations.
We propose a new method for estimating parameters that uses a data assimilation trajectory to estimate the model error. The method compares a pure model run to the analysed data assimilation trajectory and examines the differences in trajectories to get estimates of the parameters.
We have applied this method to estimate parameters in the linear advection equation. This model is used as it is understood how changes in parameters affect the dynamics of the state. We have applied our method analytically to fully understand the connections between estimated model error and differences in the true and model parameters. We shall present numerical experiments which will include the added difficulty of numerical diffusion and dispersion.

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25 Heiner Lange

Assessing the Predictability of Convection using Ensemble Data Assimilation of Simulated Radar Observations in an LETKF system

This study uses the Local Ensemble Transform Kalman Filter (LETKF) [1] to perform storm-scale Data Assimilation of simulated Doppler radar observations into the non-hydrostatic, convection-permitting COSMO model. In perfect model experiments (OSSEs), it is investigated how the limited predictability of convective storms affects precipitation forecasts. The study compares a fine analysis scheme with small RMS errors to a coarse scheme that allows for errors in position, shape and occurrence of storms in the ensemble. The coarse scheme uses superobservations, a coarser grid for analysis weights, a larger localization radius and larger observation error that allow a broadening of the Gaussian error statistics.
Three hour forecasts of convective systems (with typical lifetimes exceeding 6 hours) from the detailed analyses of the fine scheme are found to be advantageous to those of the coarse scheme during the first 1-2 hours, with respect to the predicted storm positions. After 3 hours in the convective regime used here, the forecast quality of the two schemes appears indiscernible, judging by RMSE and verification methods for rain-fields and objects. It is concluded that, for operational assimilation systems, the analysis scheme might not necessarily need to be detailed to the grid scale of the model. Depending on the forecast lead time, and on the presence of orographic or synoptic forcing that enhance the predictability of storm occurrences, analyses from a coarser scheme might suffice.

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26 Svetlana Losa

On spatially variable localisation in assimilation of satellite and in situ observations into the BSHcmod

The operational circulation model of the German Federal Maritime and Hydrographic Agency (BSH, BSHcmod) has been augmented by a data assimilation (DA) system in order to improve the hydrography forecast of the North and Baltic Seas. The DA system has been developed based on the Singular Evolution Interpolated Kalman (SEIK) filter algorithm coded within the Parallel Data Assimilation Framework. The quality of the forecast has been previously improved by assimilating sea surface temperature measurements obtained with the Advanced Very High Resolution Radiometer (AVHRR) aboard NOAA?s polar orbiting satellites. We investigate possible further improvements using in situ observational temperature and salinity data: MARNET time series and CTD and Scanfish measurements. The study addresses the problem of the local SEIK analysis accounting for the data within a certain radius. The localisation radius is considered spatially variable and dependent on the system local dynamics. As such, we define the radius of the data influence based on the energy ratio of the baroclinic and barotropic flows.

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27 Ilian Manafov

Study of fog forecast for Sofia Airport

The accurete forecast of fog is of critical importance for the operational aviation. The operational fog forecast is based on accessment of the visibitity and the hight of the low level clouds. The current operational tools at the Sofia Airport are based on synopthic analisis and regration methods. In this study we use the Numerical Wather Prediction model Weather Research and Forecasting (WRF) to study 18 fog cases for the period 2010-2012. Different model parametrizations are tested to evaluate their performance for low level inversions and for fog formation processes. The model skills in simulations of low level inversions are found to be poor likely due to lack of appropriate data assimilation procedure. Future work will concentrate on tests with assimilation of surface, upper air observations and GNSS tropspheric products as well as increase of horizontal model resolution to 1 km.

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28 Jelena Markovic

Using dual-polarized radar data in LAPS

Local Analysis and Prediction System (LAPS) is designed to accept and exploit all available data sources: surface (SYNOP, METAR data and data from automatic weather stations), sounding, satellite and radar data. The aim is to create analysed fields with the focus on the mesoscale systems. To accomplish this goal the radar data play a very important role. Doppler velocity data are used in the wind analysis using a multiple iteration successive correction technique. Radar reflectivity data are combined with the surface observations, satellite and pilot reports in the cloud analysis, which plays the important role in wind and mass dynamic adjustment. Beside these radar parameters dual-polarization provide the additional information that can be used in the cloud and precipitation analyses. Differential reflectivity, speciffic differential phase and correlation coefficient between horizontal and vertical polarized radar signal are the parameters that open the new possibilities necessary for better hydrometeor discrimination and precipitation quantification.

29 Lars Nerger

On sequential observation processing in localized ensemble Kalman filters

The different variants of current ensemble square-root Kalman filters assimilate either all observations at once or perform a sequence in which batches of observations or each single observation is assimilated. The sequential observation processing is used in filters algorithms like the ensemble adjustment Kalman filter (EAKF) and the ensemble square-root filter (EnSRF) and can result in computationally efficient algorithms because matrix inversions in the observation space are reduced to the inversion of single numbers. For large scale applications, ensemble filter algorithms require typically the application of localization. The necessary modification of the algorithm leads to an inconsistency of the update equation for the state error covariance matrix as was noted by Whitaker and Hamill (Mon. Wea. Rev. 130 (2002) 1913). Often, this inconsistency does not lead to a significant impact on the assimilation performance. However, using a simple model, we demonstrate with the EnSRF algorithm that the sequential observation processing can significantly deteriorate the assimilation performance under some circumstances. The deterioration can reach a level at which intermediate state realizations in the assimilation sequence over all observation can have a larger root-mean square error than the state estimate without assimilating any observations. This effect can be characterized to appear for small ensembles and a rather strong assimilation impact.

30 Corey Potvin

Improving storm-scale EnKF analyses and forecasts through accelerated ensemble spin-up: The 24 May 2011 Oklahoma tornado outbreak

The Warn-on-Forecast (WoF) initative seeks to develop a real-time storm-scale ensemble analysis and forecasting system that provides probabilistic guidance for tornadoes and other thunderstorm hazards. The ensemble Kalman filter (EnKF) will be an integral component of the WoF system, possibly in combination with a variational analysis method (i.e., hybrid approach). Previous studies suggest ensemble forecasts provided by a WoF system may be operationally useful despite current observational, modeling and computational limitations. However, significant challenges remain, one of which is to reduce the number of data assimilation cycles required to obtain a sufficiently accurate forecast initial condition. Critical to addressing this issue is accelerating convective ensemble spin-up ? the delayed development of newly observed storms within the ensemble. The spin-up problem arises from the poor ensemble mean analysis and covariances in/near such storms prior to the availability (and assimilation) of radar observations.
Impacts of ensemble spin-up acceleration methods are being evaluated for the 24 May 2011 Oklahoma tornado outbreak. Doppler radar observations are assimilated on a 3 km grid using the WRF-ARW model and a local ensemble transform Kalman filter (LETKF). Short-term ensemble forecasts are then initialized at various times in the LETKF analysis. The presented work focuses on improvements gained by the Running-In-Place (RIP) technique, in which observations are assimilated multiple times to maximize the information extracted during ensemble spin-up. The impact of RIP is contrasted with that of older approaches, such as using thermal bubbles to initiate convection where it is lacking in the ensemble.

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31 Corey Potvin

Removing acoustic-mode pressure oscillations from storm-scale ensemble Kalman filter analyses

When an ensemble Kalman filter (EnKF) and compressible model are used to assimilate storm-scale radar data, dynamically unbalanced analysis increments can incite high-amplitude acoustic waves and attendant pressure oscillations that preclude investigation of pressure-gradient-driven processes. Fortunately, thermodynamic retrieval techniques traditionally applied to dual-Doppler wind analyses can be modified to diagnose the balanced (uncontaminated) portion of EnKF pressure posteriors, thereby eliminating the fast-mode oscillations. The efficacy of this approach is demonstrated using a high-resolution supercell simulation as well as simulated and real EnKF supercell analyses.

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32 Attada Raju

Estimation of improvement in Indian summer monsoon circulation by assimilation of temperature profiles in WRF model

This study estimates the improvement in Indian Summer Monsoon(ISM) simulation in the Weather Research and Forecast (WRF) model by assimilating satellite retrieved temperature profiles. Two experiments are primarily carried out from 01 May to 01 October for the period of 2003 to 2011. In the first experiment reanalysis forcing is used (CTRL) for the nine year simulation and second (WRFAIRS) is same as CTRL but satellite retrieved temperature profiles are assimilated. Various statistical scores are estimated with respect to observations to quantify the improvement in the simulation when temperature profiles are assimilated. It is found that assimilation improved the distribution of sea level pressure (SLP), circulation, temperature, moisture and precipitation. Major improvements due to assimilations of temperature profiles are (1) reduction/removal of asymmetric SLP bias, (2) absence of unrealistic double Inter Tropical Convergence Zone type bias in precipitation apparent in the CTRL, (3) mostly error reduction is found over the oceans compared to that of continent, (4) minimized the temperature biases at boundary layer and midtroposphere, (5) improved the vertical wind shear over the study region (6) reduced water vapour mixing ratio errors by 0.3 to 0.6 g Kg-1 and (7) better simulation of monsoon circulation indices. This study supports that thermal forcing is the basic element of monsoon circulation which needs to be improved in WRF model for realistic monsoon simulation/ prediction. This study further speculates that temperature profile assimilation can be used to improve the convective parameterization schemes, which otherwise is a very complicated and expensive affair.

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33 Md. Majajul Alam Sarker

Impact of Data Assimilation in simulation of Thunderstorm Events using NWP

The objective of this analysis is to demonstrate the impact of data assimilation (DA) in Weather Research and Forecasting (WRF) Model in simulation of thunderstorm activities over Bangladesh and its neighborhood. The thunderstorms or Nor?westers which are regionally known as ?Kalbaishakhis? are mainly the well known short lived severe weather phenomena that cause a lot of damage to properties and loss of human lives in and around Bangladesh almost every year during the pre-monsoon season (March-May). Two moderate thunderstorm events along with squalls lashed over Ishurdi, Dhaka and Chittagong areas of Bangladesh and Shillong of India on 26 Apr 2010 and Satkhira, Rajshahi, Khepupara, Patuakhali, Dhaka and Chittagong areas of Bangladesh and Alipore, Dumdum, Haldia, Bankura, Gaya and Jamshedpur areas of India on 26 May 2010. WRF Model with horizontal resolution of 9 km and 27 vertical eta levels have been run for the period of 24 hours using NCEP-FNL data starting from 0000 UTC of 26 April 2010 and 0000 UTC of 26 May 2010 as initial and boundary conditions for these two events. YSU Planetary Boundary Layer (PBL) for boundary layer option, Rapid Radiative Transfer Model (RRTM) for long wave and Dudhia for short wave radiation scheme have been utilized to run the model. Noah Land Surface Model (LSM) and Kain-Fritsch (KF) cloud scheme are also considered in the Model. An attempt is made to simulate those cases by assimilating SYNOP and Upper Air data of Bangladesh and neighborhood using in WRF Model. The simulated rainfalls are compared with TRMM 3B42RT product and rainfall data of Bangladesh Meteorological Department (BMD) for validation procedure. The model results are also compared with satellite and RADAR imageries for validation and are utilized in explaining the development mechanism of the thunderstorms. The WRF Model products like dBZ, rainfall intensity, wind flow pattern, vertical wind shear and vertical wind velocity show the improvement after DA over control run in both the cases which are quite encouraging.

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34 Abhishek Shukla

Analysis of the 3DVAR Filter for the Partially Observed Lorenz '63 Model

The problem of effectively combining data with a mathematical model constitutes a major challenge in applied mathematics. It is particular challenging for high-dimensional dynamical systems where data is received sequentially in time and the objective is to estimate the system state in an on-line fashion; this situation arises, for example, in weather forecasting. The sequential particle filter is then impractical and ad hoc filters, which employ some form of Gaussian approximation, are widely used. Prototypical of these ad hoc filters is the 3DVAR method. The goal of this paper is to analyze the 3DVAR method, using the Lorenz '63 model to exemplify the key ideas. The situation where the data is partial and noisy is studied, and both discrete time and continuous time data streams are considered. The theory demonstrates how the widely used technique of variance inflation acts to stabilize the filter, and hence leads to asymptotic accuracy.

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35 Matthias Sommer

Estimating observation impact in a convective-scale localized ensemble transform Kalman filter

In operational weather forecasting, knowledge about observation impact, i.e.the contribution of specific observations to forecast error reduction, is crucial to refine the observing and data assimilation system. However, assessing this quantity by direct computation (data denial experiments) is usually not feasible because of the high computational cost. This has motivated the derivation of approximated forms of observation impact. If an adjoint model is available, established methods exist that give a reliable estimate. On the other hand, in an ensemble-based environment, a recently developed algorithm [1] uses the analysis and forecast deviations to approximate observation impact. This has now for the first time been implemented in the convective-scale limited-area model COSMO and has been thoroughly verified with data-denial experiments [2]. It has been found that the difference to data denial is not significant (less than 10%) and accuracy can be expected to improve further when considering longer test periods. The peculiarities for an application on this scale include a strongly non-linear behavior and a typically small localization length. While the former can be expected to be reasonably addressed by the ensemble algorithm, the latter imposes constraints for a reasonable choice of lead time. It could also be shown that valuable information, such as the detection of disadvantageous observations can be gained. This presentation shows the feasibility and distinctive features of the method for a convective-scale setup, gives examples from a pre-operational application at Deutscher Wetterdienst, and discusses the sensitivity to lead time, localization and verification norm.

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36 Julian Tödter

Land surface data assimilation with TERRA in a climate context

The land surface is known to be a key parameter in both weather and climate predictions. The initial state (temperature and moisture) of the soil ? particularly in deeper layers ? and poorly known parameters related to the soil parameterization strongly influence the simulation of screen-level variables. A well-established way to optimize the initial state, and eventually also parameters, is to perform a data assimilation cycle combining the information from model and observations.
The major challenge of land surface data assimilation in a climate context is the fact that observations, mostly by satellites, are exclusively available for the upper soil. Hence, their information has to be transferred to the deeper layers which exhibit a long-term memory with the potential of seasonal and decadal predictability.
For data assimilation, we concentrate on the land surface and use an offline version of TERRA, which can now be run on regional scales using WATCH forcing data. This model has been implemented into a Parallel Data Assimilation Framework (PDAF), which allows to apply state-of-the-art ensemble data assimilation algorithms.
This work introduces the data assimilation methodology with TERRA on the basis of observation simulation experiments to discuss algorithmic and observational properties. The focus is put on the necessary conditions to be able to estimate the deeper soil, and the feasibility of simultaneous parameter estimation. Finally, as an envisaged application, the generation of an initial soil state ensemble for Africa and Europe within the MiKliP project is outlined.

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37 Lucio Torrisi

The CNMCA Operational LETKF Data Assimilation System: recent developments

The Italian National Meteorological Center runs routinely an ensemble data assimilation algorithm based on the LETKF scheme. The CNMCA-LETKF data assimilation system is used operationally to initialize the deterministic COSMO-ME model since 1 June 2011. LETKF is running with 40+1 members having a 10 km grid spacing. The observational dataset operationally ingested comprises 4D radiosonde ascents (RAOB), surface pressure observations from land and sea stations (SYNOP, SHIP, BUOY), manual and automatic aircraft observations, atmospheric motion vectors from Meteosat7 and MSG3, European wind profilers, scatterometer winds from METOPA-B and Oceanscat2 satellites and AMSU-A radiances.
Recently a number of activities has been done to tune and improve the LETKF system. Major developments comprise:
- test of a self-evolving additive inflation using 12h-6h forecasts from the LETKF-ensemble in combination with the multiplicative inflation (relaxation to prior variance);
- monitoring and assimilation of new observations (MHS and ATMS);
- better treatment of humidity variables (i.e. test with different quality control strategies, better localization and use of pseudo-variables in the LETKF).

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38 Genta Ueno

Covariance localization with a graphical model and its application to the ensemble Kalman filter

It is known that the ensemble Kalman filter (EnKF) can estimate state variables properly using a relatively small ensemble size. Using an ensemble of much smaller size, however, the EnKF requires regularization of an ensemble covariance matrix that reduces spurious correlations between variables defined on distant grid points. One of the methods is localization of the ensemble covariance matrix using a correlation function that has a compact support.
The present study proposes an alternative method for regularizing the ensemble covariance matrix. The method assumes conditional independence between variables which is realized by imposing zero elements in the inverse matrix of the original covariance matrix. The EnKF is reformulated on the basis of the inverse covariance matrix. Since a graphical model is used in modeling the conditional independence, I call the present filtering method a graph-based EnKF (GEnKF). A numerical experiment using the Lorenz 96 model demonstrates that the GEnKF surely reduces spurious correlations and provides reasonable state estimates.

39 Michael Würsch

A Simple Dynamical Model of Cumulus Convection for Data Assimilation Research

A simplified model for cumulus convection has been developed, with the aim of providing a computationally inexpensive but physically plausible environment for developing methods for convective-scale data assimilation. This model is part of a hierarchy of models, where a stochastic toy model already exists and is the first in a series of models. The model presented is an intermediate model. An idealised convection resolving model is the last step of the hierarchy and presented in another poster.
Key processes, including gravity waves, conditional instability and precipitation formation, are represented, and parameter values are chosen to reproduce the most important space and time scales of cumulus clouds. The model is shown to reproduce the classic life cycle of an isolated convective storm. When provided with a low amplitude noise source to trigger convection, the model produces a statistically steady state with cloud size and cloud spacing distributions similar to those found in radiative-convective equilibrium simulations using a cloud resolving model.Results are also shown for convection triggered by flow over an orgraphic obstacle, where depending on the wind speed two regimes are found with convection trapped over the mountain, or propagating downstream.
The model features prognostic variables for wind and rain that can be used to compute synthetic observations for data assimilation experiments. These observation can mimic radar and radial wind observations. An LETKF is used for the data assimilation experiments which are also presented and compared to idealised experiments with COSMO-KENDA.

40 Vera Nomikou

Application and latest developments of the Local Analysis and Prediction System (LAPS) in Greece

LAPS is a 3-D mesoscale meteorological data assimilation tool that incorporates surface and upper air observations (METAR, SYNOP, satellite, soundings, radar, aircraft etc) into large-scale gridded data (as background fields) in order to produce high spatial and temporal resolution analysis fields. LAPS provides the capacity to be used standalone as an advanced nowcasting system while it can also serve as a procedure to define the initial conditions for local to mesoscale limited area atmospheric models.
LAPS has been implemented and operated for nowcasting purposes by the Harokopio University of Athens over two domains. The first domain, a coarser one, includes Europe, Middle East and North Africa and the second, a finer one, covers Eastern Mediterranean and Greece. The former uses 15 km horizontal grid increment and 41 vertical levels while the later is applied on 3 km horizontal grid increment and follows the same vertical discrimination. The system produces early and final analyses on hourly basis by assimilating METAR, SYNOP and RAOB data on GFS first-guess fields. Latest developments include the assimilation of real-time satellite precipitation estimates, allowing LAPS implementation as an early warning system for hazardous weather events over Greece.
The Hellenic Centre for Marine Research (HCMR) operates routinely LAPS and the hourly produced analyses are utilized for the initialization of the operational POSEIDON weather forecasting system.
LAPS analysis performance has been evaluated against a number of independent observations for the period of two consecutive years (2008-2009) over Greece. The statistical results suggest that the background fields play a key role in the quality of the produced analyses.

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