International Conference
on Ensemble Methods in Geophysical Sciences

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Poster Programme
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Posters can remain on display for the whole duration of the Conference. Each author will have to be in attendance from 18.00 to 19.30, either on Monday 12 or Tuesday 13 according to the schedule below. Please note that posters will have to be taken down By Friday lunch time.

Monday 12 November

Session 1. ***Particle Filters and Applications***

1 - Estimation of Ecological Model Parameters by Implicit Sampling
Brad Weir: Oregon State University – USA. bweir@coas.oregonstate.edu
Alexandre Chorin, Robert Miller, Matthias Morzfeld and Yvette Spitz

We describe a new algorithm that simultaneously estimates the state evolution and parameters of a non-linear stochastic model based on noisy observations of the state. The method approximates the probability distribution of the model solutions and parameters with an ensemble of sample values called particles: for each individual particle, it first determines the most likely values given the observed data, then samples around those values. This approach has a strong theoretical foundation, applies to non-Gaussian distributions, and can be implemented as a smoother or filter to estimate any number of model parameters, initial conditions, and/or model error covariances. We refer to it as "implicit" because it updates the particles without forming a predictive distribution of forward model integrations.
The primary motivation of this research is the estimation of marine ecological model parameters conditioned on satellite-based observations of chlorophyll. Using the values of the parameters, we hope to determine with some certainty which planktonic groups inhabit a given region of the ocean over a specific length of time. In our experience so far, the implicit method avoids the problem of sample impoverishment that hampers many other ensemble methods. Its effectiveness is particularly apparent when the true parameter and initial approximation lead to qualitatively different model outputs. We use this property to compare the effectivness of our approach with the ensemble Kalman filter (EnKF) and sampling importance resampling (SIR). The implicit estimator is asymptotically unbiased, has a root-mean-squared error comparable to or less than the other methods, and is accurate even when the probability distributions are non-Gaussian and the ensemble size is small.

2 - Stochastic level set dynamics for the tracking of closed curves from image data
Memin Etienne: INRIA – France. etienne.memin@inria.fr
Christophe Avenel: LIP6, UPMC - LIP6, Universite Pierre et Marie Curie, France
Patrick Perez: Technicolor Corporate Research, France

We introduce a stochastic filtering technique to track the state of a free curve from image data. In that purpose, we design a continuous-time dynamics that allows us to infer inter-frame deformations. The curve is defined by an implicit level-set representation and the stochastic dynamics is expressed on the level-set function. It takes the form of a stochastic partial differential equation with a Brownian motion of low dimension. In these evolution models, we propose to combine local photometric information, deformations induced by the curve displacement and an uncertainty modelling of the dynamics. Specific choices of noise models and drift terms lead to a traditional level set evolution law based on mean curvature motions, while other forms yield new

evolution laws. The approach we propose is implemented through a particle filter, which includes colour measurements characterizing the target and the background photometric probability density respectively. The associated filter capabilities are demonstrated on various satellite image sequences depicting the evolution of complex geophysical flows. The robustness and the long term performances of the method is demonstrated on 10 years of daily available satellite images related to ice density at the north pole for the tracking of an interface delineating a specified region.

3 - Object-oriented processing of CRM precipitation forecasts by stochastic filtering
Philippe Arbogast: CNRM-GAME – France. philippe.arbogast@meteo.fr
Olivier Pannekoucke, Etienne Mémin

In order to cope with position errors of mesoscale structures in cloud-resolving models it is suggested to post-process the model outputs following a fuzzy object oriented approach. The aim is to extract and track precipitating features associated with a higher predictability than the individual precipitating cells found in the forecast. The present approach uses the particle filter method to recognize patterns based on predefined texture or spatial variability of the model output. An ensemble of precipitating objects, which are then propagated in time using an advection-diffusion process, is involved. This method allows deterministic forecasts to be converted into probabilistic ones. Specific case studies supporting the ability of such ensemble predictions to improve short-range precipitation forecast skill will be shown.

4 - Implications of proposal density choices in a SIR particle filter
Andreas Rhodin: German Weather Service – Germany.

In [Leuuwen 2010] a method to enhance the particle filter with re-sampling is proposed by i) choosing a proposal density that is different from the model error pdf and ii) choosing this proposal density in a way which leads to almost equal weights of the particles in the posteriori distribution.
Here the choice of the proposal density and its implication is analysed by means of a very simple 1-dimensional example set-up: Gaussian distributions and specific choices for observational, background and model error. The qualitative 'visual' assessment is augmented by statistical considerations. The risks of choosing proposal densities which differ strongly from the model error pdf are shown and the approach to obtain almost equal weights in the prior distribution is examined critically.

References: Non-linear data assimilation in geosciences: an extremely efficient particle filter. P.J.van Leeuwen QJRMS 136:1991-1999 2010

Session 2. *Miscellaneous*

5 - Examining characteristics of analysis errors using TIGGE multi-center analyses
Thomas Hamill: NOAA Earth System Research Lab, Physical Sciences Division US

A year's worth of global analyses from multiple operational centers were recently downloaded and examined using data from the TIGGE THORPEX database. Examining such differences between the analyses may be useful both as a diagnostic for detecting when one center is radically inconsistent with the other centers, and it may provide some general guidance on the structure of analysis errors for ensemble initialization.
The examination of differences between the centers shows that there were surprisingly large differences between the centers' analyses. Near-surface temperature analyses differed instantaneously and even in time averages by 5K or more. Some regions such as subtropical oceans had analysis differences in 850 hPa temperatures of several K, and tropical wind analyses differed by 5 ms-1 or more, even in time averages. In some analyses, southern-hemisphere extratropical cyclones were completely missing.
The spectral structure of ensemble Kalman Filter perturbations from the Canadian Meteorological

Center and NOAA were also compared against operational NOAA/NWS "ensemble transforrm with rescaling" perturbations and ECMWF perturbed obs/4D-Var/singular vector perturbations. The spectral structure of the multi-center analysis differences were used as a basis for comparison. Generally, the ensemble perturbation methods showed a lack of sufficient amplitude at the planetary scales, as none were designed to account for systematic biases in the large-scale analyses.

6 - Evaluation of uncertainty of future change in precipitation by global warming ensemble projections using 60-km mesh global atmospheric models
Shoji Kusunoki: Meteorological Research Institute (MRI) – Japan

Uncertainties of future change in precipitation were evaluated for ensemble simulations of global warming. Time-slice experiments were conducted using 60-km mesh global atmospheric model (MRI-AGCM3.1H and 3,.2H) which well reproduces extreme precipitation events and tropical cyclones compared with coarser horizontal resolution models. For present-day climate, observed historical Sea Surface Temperature (SST) was prescribed from 1979 to 2003 (25 years). For future climate from 2075 to 2099 (25 years), change in the multi-model ensemble of SSTs projected by atmosphere–ocean general circulation models (AOGCMs) for Couple Model Inter-comparison Project 3 (CMIP3) was superposed to the observed historical SST. A1B emission scenario is assumed. To evaluate uncertainty of projection, ensemble simulations were conducted using version 3.1H of the 60-km model with four different SSTs and three different atmospheric initial conditions for future climate (experiment 1). Moreover, ensemble simulations were conducted using version 3.2H of the 60-km model with four different model physics (cumulus convection scheme) and four different SSTs (experiment 2). Classical ANalysis Of VAriance (ANOVA) was applied for change of seasonal and annual average precipitation. Experiment 1 indicates the contribution of SST to the total variance is generally larger than that of initial condition (internal chaotic variability of atmosphere), but some regions of mid-latitude are affected by internal chaotic variability of atmosphere. Experiment 2 indicates the contribution of cumulus convection scheme is generally larger than that of SST, but some regions over the Pacific Ocean and Indian Ocean are strongly influenced by SST.

7 - Cyclone Aila Moisture Effects On Heavy Rain And Flooding In Bangladesh, Bhutan, Ne-India And Nepal
Mohan Kumar Das: SAARC Meteorological Research Centre (SMRC) – Bangladesh

Cyclone AILA-2009 was of moderate intensity that ravaged south western part of Bangladesh badly. Alongside, it ravaged West Bengal of India, eastern Nepal and southern Bhutan. Due to torrential rain these four countries experienced flooding effects. A series of heavy rainfall events caused devastating floods across portions of south central and south west Bangladesh into north western Bangladesh, south eastern Nepal and Bhutan from May 26-27, 2009. The occurrence of both a frontal and meso-scale convection pattern and the entrainment of tropical moisture from western Bay of Bengal (BoB) combined to produce heavy rainfall. The wet spell episode persisted over a two days period. An extensive area with storm totals of 25 to 50 mm stretched from south west Bangladesh into south eastern Nepal and Bhutan. This is a case study examining the meso-scale, upper air and hydro-logic aspects which led to the prolonged heavy rain and flood episode. Advanced Research WRF (ARW) Model with horizontal resolution of 9 km x 9 km, 50s time step and 27 vertical levels has been used to simulate the nature of Cyclone AILA and its associated wind, rainfall etc. Six hourly Final Reanalysis (FNL) data of National Centers for Environmental Prediction (NCEP) were used as input to WRF-ARW Model for the simulation of "AILA". The model results are compared with the TRMM, Kalpana-1 images and the India Meteorological Department (IMD) predicted results. Further, the intensity of the events generated from the simulations is also compared with the national meteorology predictions in order to evaluate the model performance.

8 - Improved Monsoon Rainfall in Regional Climate Model Using Data Assimilation

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Indian Summer Monsoon (ISM) is one of the spectacular features of the global atmospheric general circulation. In recent years, attempts have been made to simulate the climate features by regional climate models. Although the accuracy of the regional atmospheric models has improved dramatically during the past decades, many sources of error still remain. The sources of errors in the numerical weather prediction (NWP) models can be classified into two categories. One is from the model used; reflecting the imperfection of model in resolving the forcing present in the atmosphere and the other source is from observing the initial true state of the atmosphere. The present study examines the impact of assimilation of temperature and water vapour profiles from Atmospheric Infra-red Sounder (AIRS) data and Radiosonde observations on WRF for simulation of monsoon active period during 2010.

The model used herein is the Weather Research and Forecasting model. The NCEP/NCAR Reanalysis data is used to determine the initial and boundary conditions required for the model integration. For the model validation, ERA,TRMM-3B42,IMD gridded rainfall and Atmospheric Infra-red Sounder (AIRS) satellite data used for this study. Upper air observations are also used for assimilating into model. Model has been integrated for 15 days, starting from 25 June, 2010 to 10 July 2010.

Analysis revealed that the assimilated profiles of temperature and water vapour are improved the model simulation relatively well. The Root Mean Square Error between IMD and -CTRL is 5.96 mm/day. With Assimilation, the Root Mean Square Error between IMD and Model is reduced and its value is 3.62 mm/day. Rainfall patterns are well improved over central Indian region as well northern part of country reasonably good when compared to model CTRL experiment against to observations (IMD, TRMM). Figure 2, showing that the Rainfall time series over central Indian region. It is showing that the rainfall has good improved with the assimilation when compared to CTRL run against to IMD as well as TRMM observations. The vertical structure of the Temperature (K), water vapour mixing ratio(g/Kg), and vorticity(1e-4) components are improved with assimilation compared to CTRL experiment.

In Future study, the same will be checked with Advance assimilation Techniques such as Variational and Ensemble Methods.

9 - Flow-dependent wavelet modelling of background error correlations

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Loik Berre, Gerald Desroziers

A wavelet formulation on the sphere is considered for modelling heterogeneous background error correlations for the Meteo-France global Numerical Weather Prediction model. This approach is compared to the operational spectral formulation, which is horizontally homogeneous to a large extent. Moreover, while this wavelet formulation is used operationally at ECMWF to specify heterogeneous but static correlations, a flow-dependent wavelet representation of correlations is investigated in this study.

Diagnostic studies have been conducted to examine geographical and temporal variations of 3D correlations over the whole globe. The results show the ability of wavelets to represent horizontal and vertical heterogeneities of correlations. For instance, the contrast between relatively broad horizontal correlations in the tropics and sharp ones in the mid-latitudes is well represented by the wavelet formulation. The dependence of correlations on the weather situation is also visible, with smaller correlation length-scales near mid-latitude lows. The impact of the flow-dependent formulation on the forecast quality will also be discussed and illustrated.

10 - Variational organization of modeling technology for environmental problems

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An approach to construction of methods solving direct and inverse problems for studies of natural processes with numerical models and all accessible observational data is presented. The focus is on the models of atmospheric hydrodynamics and chemistry. The approach is based on variational principles. They allow one to concordantly describe a variety of multi-scale processes and to build an optimal modelling technology.

The models of processes are considered to contain different kinds of uncertainty. This fact is denoted by the uncertainty functions that explicitly introduce some flexibility into the rigid structure of the models. A corresponding weak-constraint variational principle is formulated. The additional terms describing the consolidated measure of uncertainty are included in it. Combined analysis of the calculated model state, adjoint, sensitivity, and uncertainty functions gives the base for solution of environmental problems.

In particular, introduction of the uncertainty functions into the modelling system simplifies the structure of 4D-VAR data assimilation algorithms. In essence, these functions play the role of control parameters for minimization of the goal functional of variational principle and introduce the features of regularization into the process of inverse problem solution. In the frames of decomposition and splitting methods, we take the observation window equal to the step of model discretization in time. All assimilation procedures are realized by direct algorithms without iterations. This allows us to assimilate all accessible information on meteorological and chemical state functions.

If a problem suffers from observational data deficiency then we should get additional information involved with the use of ensemble technique. To make scenario calculations in our approach we have built informative bases with the help of orthogonal decomposition of the dynamics phase spaces of the processes under study. We use the following method. The sets of vectors of the state functions, calculated by means of non-linear models of processes, are interpreted as elements of the linear span of Krylov type spaces that are usually used in linear algebra. The functional content of the span is structured as a rectangular matrix. Further, the orthogonal decomposition of the matrix with the use of SVD technique gives the required basis. It is used for analysis of the structure of the phase spaces with an account of the scales of disturbances and for formation the constructive elements for organization of scenario ensembles as well as for analysis of the ensemble calculation results.

11 - Analysis of Integrated Forecasts from Various Combinations of NWP Models

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This study presents an analysis of observation data and NWP models as background grid data to generate optimal integrated forecasts for nowcasting up to 6 hours. Since there is a general lack of numerical models specifically designed for nowcasting, different numerical models and / or ensembles which were originally designed for short or midterm forecasts are now also being used for nowcasting. Each NWP model has its own strengths and limitations, and their forecast performance often varies in relation to time, location and other forecasting variables. A novel weighting, evaluation, bias correction and integrated system (WEBIS) has been developed at Environment Canada for generating nowcasts by integrating observation data with available NWP

forecasts. In order to know how many NWP models are sufficient to obtain optimal nowcasts and how NWP model forecasts affect integrated nowcasts, different integrated models with various combinations of NWP models are tested.
In this study, three NWP models are used individually and collectively as background models for generating integrated nowcasts. Verification is performed at two Canadian airport locations (CYYZ - Toronto International Airport and CYVR - Vancouver International Airport) over the winter and summer seasons. By analyzing the verification of forecasts, the integrated models (using 1 to 3 NWP models) were found to produce more accurate forecasts for 5 selected forecast variables (temperature, relative humidity, wind speed, wind gust and wind direction) than using either the NWP model forecasts or an objective analysis of observed data alone, regardless of season and location. The integrated methods greatly improved forecast accuracy and reduced errors.

12 - Assimilation of sea surface height into HYCOM over the Atlantic based on multivariate ensemble statistics methods
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Konstantin Belyaev, **Davi Mignac Carneiro**, Leonardo Nascimento Lima

Along-track sea surface height anomalies (SSHA) observations from Jason-1 and Jason-2 over the North and South Atlantic were assimilated into the Hybrid-Coordinate Ocean Model (HYCOM), configured with 1/4 degree of horizontal resolution and 21 vertical layers. The assimilation methods were based on the multivariate ensemble statistics and included the Optimal Interpolation (OI) method, Ensemble OI (EnOI) and others. The ensemble statistics were based on an eight-year run forced by the NCEP/NCAR atmospheric reanalysis, after 20-year spin-up with climatological forcing.
The assimilation runs were analyzed and compared with a control run performed with the same conditions of the assimilation run but without assimilation. The impact of assimilation of SSHA on other physical parameters – such as temperature, salinity, velocities and particularly model layer thicknesses – was studied. Also, sensitivity studies associated with technical aspects of the assimilation methods were carried out. This work is part of the effort to implement a multivariate assimilation scheme in operational ocean forecasting system by the Brazilian Oceanographic Modelling and Observation Network (REMO)
(www.rederemo.org).

13 - A variational approach for retrieving rain rate combining information from rain gauges, radar and microwave links.
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Alexis Berne, Peter Jan van Leeuwen, Robin Hogan

Accurate and reliable rain rate estimates are crucial for various applications (flood forecasting, road traffic, agriculture to list a few). As a consequence rain sensors of different types have deployed in many regions. In this work measurements from different sensors, namely rain gauges, radar and microwave links, are combined to estimate with greater accuracy the distribution and intensity of rainfall. The objective is to retrieve the rain rate value that is consistent with all these measurements while incorporating the uncertainty due to the indirect measurements and the different technologies applied. By focusing on static (i.e., time-independent) Gaussian case, assuming our problem is not grossly non-linear, we implement the Gauss-Newton method to solve the cost function containing proper error estimates from all sensors. This variational approach is a standard in data assimilation. It is mathematically rigorous and takes full account of errors sources. Furthermore, the method can be flexibly adapted to apply additional data sources. The proposed approach is tested assimilating data from 14 rain gauges and 14 operational microwave links located in the Zurich area (Switzerland) of about 20x23 km to correct the prior rain rate provided by the operational radar rain product from MeteoSwiss.

14 - Bayesian inference of wind drag parameters at high wind speeds using a polynomial chaos surrogate

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Justin Winokur, Alen Alexanderian, Ashwanth Srinivasan, **Mohamed Iskandarani** (1), William C. Thacker, and Omar M. Knio
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We introduce a three-parameter characterization of the wind-speed dependence of the drag coefficient and infer values for these parameters from AXBT temperature data obtained during typhoon Fanapi. Our approach relies on Bayesian inference to sharpen initial estimates of the uncertain drag parameters. The efficiency of our approach stems from using polynomial expansions to build an inexpensive surrogate for the high-resolution forward model. The surrogate is built through an adaptive ensemble strategy that continuously probes the sensitivity of the model to the uncertain parameters while providing an estimate of the approximation error incurred. Our results indicate that in the presence of hurricane winds the wind drag coefficient saturates at about 2.3e-3 at the corresponding wind speed of 34 m/s.

15 - Methods of optimal planning for remote sensing experiment in problems of satellite meteorology.

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The number of used narrow-band spectral channels increased in satellites instruments to hundreds and even thousands, due to recent developments of technologies. They are measuring radiation in wide area of ranges: from ultra-violet to distant infra-red. The comparison of various approaches for a selection of the most "informative" channels represents a certain scientific and practical interest. In our work the techniques of an optimum choice are considered for spectral channels with the fixed and variable widths.
Practically all known methods of the solution of inverse problems of satellite meteorology use certain a-priori information on required parameters. For the variety of methods the statistical information is available for vectors of restored parameters, such as noise characteristics of the satellite radiometer.
The following methods of the optimal planning were employed for a remote sensing satellites experiments: DRM(analysis of Data Resolution Matrix), DRM(SVD), Jacobians, Iterations (selection of the satellite channels is defined by Entropy Reduction), pseudo channel technique (spectral channel with variable width - based on maximizing determinant of Fisher's information matrix). For the inverse problem the method of the best linear estimate and variational technique were used. The proposed technique was employed for remote sensing of the atmospheric and surface parameters.

16 - Assessment of add-value of multi-model ensemble dynamical downscaling in Japan

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Climate change caused by human activities will continue for centuries. It will need at least several decades until mitigation will take effect. It is necessary to put adaptation together immediately. The impacts and potential applications of interest to the stakeholders are mostly at regional and local scales. Users of climate scenarios produced by global climate models with coarse grid-spacing have been dissatisfied with the inadequate mismatch of spatial scale. Downscaling technique is used to obtain the regional climate scenarios, especially in regions of complex topography,

coastlines, and in regions with highly heterogeneous land surface covers where those results are highly sensitive to fine spatial scale climate processes. Dynamical and statistical downscaling techniques available for generating regional climate information have the respective strengths and weaknesses.
We quantified the confidence and uncertainties of multi-model ensemble dynamical downscaling where the lateral and bottom boundary conditions were obtained from Japanese 25-year ReAnalysis (JRA-25) and CGCM (CMIP run). We assessed the several aspects of value (skill) added by the multi-model ensemble downscaling to climate simulations in Japan. Based on the lessons learned from the multi-downscaling project in Japan (S5-3) and the Research Program on Climate Change Adaptation (RECCA), "added value" and "predictability" of multi-model ensemble downscaling to provide scientific knowledge for sustainable development by adapting to climate change is discussed.

17 - Assimilation of Aerosol Observations in GEOS-5.
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A. da Silva, P. Colarco, A. Darmenov, R. Govindaraju

GEOS-5 is the latest version of the NASA Global Modelling and Assimilation Office (GMAO) earth system model. GEOS-5 contains components for atmospheric circulation and composition (including data assimilation), ocean circulation and biogeochemistry, and land surface processes. In addition to traditional meteorological parameters, GEOS-5 includes modules representing the atmospheric composition, most notably aerosols and tropospheric/stratospheric chemical constituents, taking explicit account of the impact of these constituents on the radiative processes of the atmosphere.
The assimilation of Aerosol Optical Depth (AOD) in GEOS-5 involves very careful cloud screening and homogenization of the observing system by means of a Neural Net scheme that translates MODIS radiances into AERONET calibrated AOD. These measurements are further quality controlled using an adaptive buddy check scheme, and assimilated using the Local Displacement Ensemble (LDE) methodology. For this analysis, GEOS-5 runs at a nominal 50km horizontal resolution with 72 vertical layers (top at ~85km). GEOS-5 is driven by daily biomass burning emissions derived from MODIS fire radiative power retrievals.
We present a summary of our efforts to validate the GEOS-5 assimilated aerosol fields by comparing to independent in-situ measurements (AERONET and PM2.5 surface concentrations). By simulating aerosol attenuated backscatter at 532nm, we use CALIPSO Level 1.5 data for the year 2011 to evaluate the vertical structure of our aerosol estimates.
Finally, as part of the ongoing effort towards the assimilation of CALIPSO data in GEOS-5 we will describe an optimal estimation algorithm to derive aerosol extinction profiles based on CALIPSO attenuated backscatter data with GEOS-5 extinction profiles used as prior. This algorithm uses the same Local Displacement Ensemble (LDE) methodology adopted for the GEOS-5 aerosol data assimilation. These GEOS-5 based extinction profiles will be closely compared to the extinction profiles available in the CALIPSO Level 1.5 files.

18 - Ensemble downscaling prediction experiment of summertime cool weather in northeastern Japan caused by local wind, "Yamase"
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Sha Weiming, Toshiki Iwasaki

Yamase, a north easterly from the Okhotsk high, brings anomalously cool and cloudy days in summer on the Pacific coast of north eastern area of Japan. Yamase is heavily affected by complex terrain because of its shallow structure. In order to reproduce explicitly the effects of the small scale phenomena, high resolution model is necessary. Here, we study the performance of medium-range ensemble downscaling prediction of the Yamase event.
In dynamical downscaling, lateral boundary conditions are derived from the forecasting data calculated with low resolution global model. To improve reliability of forecasting

with dynamical downscaling, it seems suitable to use global ensemble forecasting data as lateral boundary conditions. In this study, ensemble forecast data (horizontal resolution = 1.25◦; ensemble size = 9) were adopted as lateral boundary conditions to investigate the effect of ensemble downscaling. The horizontal resolutions were set to 25km, 5km and 1km in both downscaling experiments.
Preliminarily, in a perfect boundary experiment using the reanalysis, JRA-25, we confirmed that increasing resolution decreases the warm bias of the surface mean temperature. This is because the downscaling reproduces local circulation and cloud detail properly. In ensemble downscaling experiment, the ensemble mean forecast of downscaling is a little worse than that of global model. The spread is greater in downscaling forecast than in global model. This is because the downscaling effects are different depending on members. The results indicate the possibility of probabilistic prediction based on the spread of mesoscale phenomena.

Session 3. *Probabilistic Prediction*

19 - Probabilistic Forecasts Using Analogs in the Idealized Lorenz96 Setting
Jakob W. Messner: Institute of Meteorology and Geophysics, University of Innsbruck, Austria
Georg J. Mayr

Three methods to make probabilistic weather forecasts by using analogs are presented and tested. The basic idea of these methods is that finding similar NWP model forecasts to the current one in an archive of past forecasts and taking the corresponding analyses as prediction should remove all systematic errors of the model. Furthermore, this statistical post-processing can convert NWP forecasts to forecasts for point locations and easily turn deterministic forecasts into probabilistic ones. These methods are tested in the idealized Lorenz96 system and compared to a benchmark bracket formed by ensemble relative frequencies from direct model output and logistic regression. The analog methods excel at longer lead times.

20 - Optimization of the Analog Ensemble Method
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Luca Delle Monache, Daran Rife, Badrinath Nagarajan

An analog ensemble is constructed by matching up the current forecast from a numerical weather prediction model with similar past forecasts, then using the past verifying observation (or gridded analysis) from each match as an ensemble member. Initial results indicate that when this approach is fully localized, an analog ensemble may provide the best efficacy for production of skilled probabilistic forecasts. The analog ensemble has several very attractive features including use of a higher resolution model (since only 1 real-time forecast is needed), no struggling with initial condition and model perturbation strategies, and a natural ability to produce reliable forecasts (i.e., no post-processing required).
This follow-on study investigates various aspects of analog ensemble design optimization:
a) A longer training period increases skill as better analogs are found, but requires generation of a reforecast dataset. So can we identify an optimal trade-off? Additionally, fairly short training periods can produce skilled predictions so can we find a minimum training?
b) The optimal ensemble size appears to be highly variable so that the number of members to use should be adaptable.
1. As training data is decreased and/or the number of members is increased, the additional weaker analogs tend to decrease overall skill (primarily resolution). But using too few members reduces skill due to sampling errors, so an optimal balance is sought.
2. At early lead times, the skill of each member is highly dependent on the quality of its analog, which decreases steadily as more analogs are selected, thus suggesting use of fewer members. At longer lead times, after the onset of error growth, member skill is more dependent on random forecast error rather than analog quality, suggesting more members be used.
3. It is difficult to find a lot of good analogs for an extreme forecast (based on model

climatology), suggesting that fewer members should be used provided that reliability is maintained.
c) Accounting for the relative skill of the members (and/or strength of the analogs) may improve the skill of probabilistic predictions.
d) Careful selection of predictor variables and their relative weights are important factors in the analog search algorithm.
*An additional question is whether the analog ensemble can capture flow-dependent uncertainty as well as an NWP ensemble. Could the best approach be a hybrid ensemble where m analogs are found for each member of a small n-member NWP ensemble, to produce a total of m*n members? Initial results indicate that the hybrid ensemble is superior to the NWP ensemble, but that the pure analog ensemble (using a higher resolution model) still provides the most skill at the lowest cost. The power of analog ensemble may be derived from its ability to resolve smaller scale phenomena and accurately depict those phenomena's uncertainty.*

21 - A Probabilistic Forecast for Rainfall based on Bayesian estimation methond and Its Preliminary Experiments over china
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HAN Yanhong, JIAO Meiyan, CHEN Fajing

The paper applies BPO(Bayesian Processor of output) method based on Bayesian theory to the probabilistic method of rainfall ensemble product. Using ensemble prediction data and historic observational data, we develop a rainfall probability forecast model, and then revise a set of precipitation predicted value into a set of Bayesian precipitation probability forecast in the form of continuous probability distribution or continuous probability density. Besides, we obtain a group value of IS (Informativeness Score), which can express the prediction ability of each ensemble member. Furthermore, we fuse the probability forecast results of each member into an integration Bayesian precipitation probability forecast on the basis of IS and test the results with CRPS. Experiments results show that the reliability of integration Bayesian precipitation probability forecast is higher than ensemble direct probability forecast.

22 - How large should an ensemble be?
Reason Machete: University of Reading - United Kingdom. r.l.machete@lse.ac.uk
Leonard A Smith, London School of Economics

Ensemble forecasting involves propagating forward in time an ensemble of points sampled from an initial distribution. The ensemble forecasts can then be converted to probabilistic forecasts. It has been suggested that only a few ensembles are sufficient to obtain accurate estimates of the underlying distribution. It is shown in this paper that this conclusion is questionable, both within a pure density estimation context and forecasting. In the context of forecasting, both the perfect and imperfect model scenarios are considered. The effect of increasing the ensemble size is highlighted via the effective growth rate of the wealth of users with competing ensemble sizes.

23 - Statistical post-processing of ensemble forecasts: nudging and re-weighting
Frank Kwasniok: University of Exeter - United Kingdom

A new method is proposed for statistical post-processing of ensemble forecasts. Small corrections to the ensemble or a re-weighting of the ensemble members are applied in order to improve the internal statistical consistency of the ensemble forecasts. For example, the spread-skill relationship of an ensemble can be rectified in this way, leading to better calibration of the forecasts. The method is explored in the Lorenz '96 system; substantial improvements over the raw ensemble are achieved both in deterministic and probabilistic prediction skill.

24 - Calibration of probabilistic 100 m wind speed forecasts using reforecasts

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Lueder von Bremen

The expansion of wind energy requires the safe integration of wind power into the European power supply system. Accurate forecasts of wind speed and power production up to 72 h ahead are thus necessary to ensure the reliability of the power supply system. Unlike deterministic wind forecasts, probabilistic wind forecasts obtained from ensemble prediction systems (EPS) provide end-users with the forecast uncertainty of the expected wind power production.
However, probabilistic wind speed and power forecasts obtained from raw wind ensembles are subject to forecast-bias and dispersion errors. Recently, calibration techniques were developed using 'reforecasts' and model analyses as forecast-observation training dataset to correct the deficiencies of the ensemble forecasts. The advantage of using reforecasts for the calibration of ensemble forecasts is not only the long data record of the training dataset but also the production of the training data with the same and latest model cycle.
In this study, an improved reforecast-calibration method is presented which is based on mapping the wind speed quantiles of historic cumulative distributions to the observed cumulative distribution. The mapping of the quantiles allows the calculation of the calibration parameters that are used for correcting the ensemble wind forecasts. The advantage of this reforecast-calibration method is that the calibration uses measurements with local wind characteristics instead of model analyses. Furthermore, the trajectories of the ensemble are conserved during the calibration.
Here, the calibration method is evaluated for the location of the offshore measurement mast FINO1 in the German Bight. The reforecast dataset of 100 m wind speed is provided by the European Center for Medium Range Weather Forecasts (ECMWF) and consists of five ensemble members. The reforecasts are operationally produced once a week, with start dates within the past 18 years. The 102 m wind speed observations at the platform FINO1 are available for the years 2004-2011 with a time resolution of 10 min. The ECMWF reforecasts and observations for the FINO1 location are used as the training dataset to calibrate ECWMF's EPS which has 51 ensemble members and forecast steps of 3 h. To evaluate and calibrate the ensemble forecasts, skill scores like the Brier Skill Score, CRPSS and reliability diagrams are used. The probabilistic skill scores show that the reforecast-calibration method leads to a clear improvement over the raw ensemble wind forecast.

Session 4. ***Kalman and Hybrid Filters. Theoretical Aspects.***

25 - Ensemble Kalman filtering with residual nudging
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Ibrahim Hoteit at KAUST, Saudi Arabia

Covariance inflation and localization are two important techniques that are used to improve the performance of the ensemble Kalman filter (EnKF) by (in effect) adjusting the sample covariances of the estimates in the state space. In this contribution an additional auxiliary technique, called residual nudging, is proposed to monitor and, if necessary, adjust the residual norms of state estimates in the observation space. In an EnKF with residual nudging, if the residual norm of an analysis is larger than a pre-specified value, then the analysis is replaced by a new one whose residual norm is no larger than the pre-specified value. Otherwise the analysis is considered as a reasonable estimate and no change is made. Rule for choosing the pre-specified value is suggested. Based on this rule, the corresponding new state estimates are explicitly derived in case of linear observations. Numerical experiments in the 40-dimensional Lorenz 96 model show that introducing residual nudging to an EnKF may improve its accuracy and/or enhance its stability against filter divergence, especially in the small ensemble scenario.

26 - Ensemble-Based Ocean Data Assimilation: Blending Dynamic and Static Estimates of

Error Covariance
Balu Nadiga: Los Alamos National Lab. - USA. balu@lanl.gov
William Casper

We are interested in global ocean data assimilation for the purpose of initializing climate models. We consider ensemble-based data assimilation in the context of the POP (Parallel Ocean Program) OGCM and ask the specific question of whether there is a state of the modelled ocean circulation that is compatible with observations of the ocean as represented in the World Ocean Database when the OGCM is forced by CORE v2 (Coordinated Ocean Reference Experiment version 2) estimate of the atmosphere.
A frequent problem that plagues ensemble-based ocean data assimilation is filter divergence wherein poor or collapsed ensemble spread is interpreted by the filter as high certainty in the model forecast forcing it to neglect observations---in turn leading to increased RMS error---and an eventual failure of the assimilation. A blending of the dynamically estimated, ensemble-based error covariance with a static background estimate of the error covariance allows us to circumvent such a problem and enables successful data assimilation. Results from a successful assimilation experiment will be discussed.

27 - On Improvement of Ensemble Transform Kalman Filter with Nonlinear Observational Operator
Guocan Wu: Beijing Normal University – China. gcwu@bnu.edu.cn
Xiaogu Zheng, Liqun Wang
For non-linear observational operators in data assimilation, a new methodology of estimating inflation factor is proposed in the framework of ensemble transform Kalman filter (ETKF). The methodology is still based on observation-minus-forecast residuals, but inflation factor is estimated using the second-order least squares estimation. The advantage of this approach is that the observational operator is no longer restricted to be tangent-linear. Moreover, we proposed two fast calculation algorithms for special cases of observational operator.
Through imperfect model assimilation experiments on two well-known chaotic and non-linear observational operator systems, Lorenz-40 model and Two-dimensional Shallow Water Equation model, It is demonstrated that our proposed approaches are more effective and accuracy.

28 - Ensemble-smoothing under the influence of nonlinearity
Lars Nerger: Alfred Wegener Institute for Polar and Marine Research – Germany.
Svenja Schulte, University of Bremen, Germany
Angelika Bunse-Gerstner, University of Bremen, Germany

Ensemble-smoothing can be used as a cost-efficient addition to ensemble square root Kalman filters to improve a reanalysis in data assimilation. To correct a past state estimate, the smoothing method utilizes the cross-covariances between the present filtered state ensemble and a past ensemble at the time instance where the smoothing should be performed.
Using the cross-covariances relies on the assumption that the dynamics of the system under consideration are linear. Thus, for non-linear models, it can be expected that the smoothing is suboptimal. We discuss the influence of non-linearity on the performance of ensemble-smoothing based on numerical experiments with small models. The experiments show that there exists an optimal smoothing time interval, which depends on the strength of the nonlinearity. Under some circumstances, the smoothing can also deteriorate the quality of state estimates compared to assimilating only current observation by filtering.

29 - Preservation of physical properties with ensemble-based Kalman filter algorithms

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Dennis B. McLaughlin, Massachussetts Institute of Technology, Cambridge, USA
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One of the principles used often in developing discretization schemes for geophysical fluid dynamics is to maintain conservation properties that characterize the flow. The most basic of these integral constraints is the conservation of total mass. In this work we focus on ensemble-based sequential data assimilation algorithms and show that even for linear dynamics it is typical in practice that the state estimates lose total mass. Total mass is sometimes lost by producing analyses that have negative values. Two approaches are investigated to ensure both positivity and conservation of total mass, without resorting to a posteriori adjustments. One is to impose a constraint on the error covariances and the other is to impose a constraint in the cost function. We examine the extent to which imposing mass conservation requirements in data assimilation algorithms changes the assimilation results and demonstrate the impact of imposing mass conservation on prediction in simple experiments.

30 - Dissipation in Ensemble behaviour

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Steve Cohn, Global modeling and assimilation office, NASA Goddard Space Flight Center, Maryland, USA
Sergey Skachko, Belgian Institute for Space Aeronomy, BIRA-IASB, Brussels, BELGIUM

Numerical models almost always exhibit spurious dissipation. Although dissipation can be mild in deterministic prediction of the state, it can pose a serious problem in the context of filtering, creating large, state-dependent loss of error variance. In EnKF the ensemble mean is spatially more smooth than each ensemble members, and this leads to a spurious loss of total energy in ensemble perturbations. Spurious loss of variance may be eliminated by undoing the spurious dissipation that acts on the perturbations. Using a one-dimensional transport on a periodic domain and two-dimensional transport problem on a sphere, the issue of loss of variance is examined from an analytical, KF, EnsKF point of views. To restore the variance we examine the effect of covariance inflation, anti-dissipation, and using a model solution and not the ensemble mean to compute the perturbations.

31 - Spectral consistency for ensemble square root filters

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Spectral properties of the assimilated data and numerical model usually differ. In addition, ensemble Kalman filter algorithm depending on the size of the ensemble and choice of the localization matrix will modify spectral properties of the analysis. In this work we investigate the relation between the spectral properties of the observations, localization matrix used for ensemble Kalman filter, as well as the numerical model. Further, in the context of reduced order analysis there is a error contribution which is linked to the fraction of the background error that is not included in the analysis reduced space. Having in mind the spectrally consistent approach, the proper way of including this error in reduced rank algorithms and ways of modeling its covariance are discussed.

Session 5. ***Kalman and Hybrid Filters. Continuation and Applications***

32 - Towards Data-Driven Simulations of Wildfire Spread using Ensemble-based Data Assimilation

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Jean-Michel Bart, Bénédicte Cuenot, Sophie Ricci, Arnaud Trouvé

Real-time predictions of a propagating wildfire remains a challenging task because the problem involves both multi-physics and multi-scales. The propagation speed of wildfires, also called the rate of spread (ROS), is indeed determined by complex interactions between pyrolysis, combustion and flow dynamics, atmospheric dynamics occurring at vegetation, topographical and meteorological scales. As a wildfire generally features a front-like geometry at regional scales, current operational models simulate it as a propagating front at a ROS based on a semi-empirical model due to Rothermel. In these models, the ROS is treated as a simplified function of vegetation, topographical and meteorological properties. For the fire spread simulation to be predictive and compatible with operational applications, the uncertainty on the ROS model should be reduced. As recent progress made in remote sensing technology provides new ways to monitor the fire front position, a promising approach to overcome the difficulties found in wildfire spread simulations is to integrate fire modelling and fire sensing technologies using data assimilation (DA).
For this purpose we have recently developed a prototype data-driven wildfire spread simulator in order to provide optimal estimates of poorly known model parameters. The wildfire spread simulation capability considers a regional-scale fire spread model that is informed by an assumed set of real-time observations of the fire front location. Our previous work led to the evaluation of the DA algorithmic methodology for improving fire spread simulation performance [*]. The capability was based on the best linear unbiased estimator (BLUE) algorithm to correct vegetation parameters of the ROS model. It was able to accurately track a small-scale controlled grassland fire experiment. However, the model correction was limited to the estimation of a pair of parameters and the BLUE algorithm assumed a questionable linear relation between a perturbation in the model parameters and the resulting change in the fire front positions.
In this perspective, this study addresses the challenges specific to the development of a robust DA methodology adapted for more realistic wildfire spread. The capability has been extended to an Ensemble Kalman Filter (EnKF) algorithm based on a parallel computing platform. This study compares the performance of the BLUE and EnKF algorithms in a series of tests taking into account topographical and wind conditions. The EnKF algorithm shows its good ability to track the fire spread and ensures a good accounting for the sensitivity of the simulation outcomes to the control parameters.

[*] Rochoux, M.C., Delmotte, B., Cuenot, B., Ricci, S., and Trouvé, A. (2012) "Regional-scale simulations of wild-land fire spread informed by real-time flame front observations", Proc. Combust. Inst., 34, submitted for publication.

33 - Development of a 4D-REKF ensemble data assimilation and forecasting system and a comparison with Ensemble Kalman Filter and WRF3/4DVAR

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Yubao Liu, Yonghui Wu, Linlin Pan, Al Bourgeois, Jason Knievel, Scott Swerdlin, Xin Zhang and Xiang-Yu Huang, John Pace, Frank Gallagher and Scott Halvorson

A Four-Dimensional Relaxation Ensemble Kalman Filter (4D-REKF) modelling system for mesoscale analysis and forecasting has been developed at NCAR. 4D-REKF is built upon the multi-model (MM5 and WRF), multi-approach (perturbations), and multi-scale (nested-grid) E-RTFDDA (Ensemble Real-Time Four-Dimensional Data Assimilation and forecasting system). E-RTFDDA has been deployed for operational support at US Army test ranges since August 2007, and for wind energy prediction for Xcel Energy since May 2010. 4D-REKF is implemented by replacing the empirical spatial weight functions in the traditional Newtonian-relaxation station-nudging FDDA formulations with the Kalman gains computed with a local ensemble Kalman Filter (LEKF) scheme. 4D-REKF retains and leverages the advantages of both traditional Newtonian-relaxation

and Ensemble Kalman Filter data assimilation schemes. It eliminates the ad-hoc nature of the spatial weight functions in typical station-nudging FDDA formulation; and meanwhile, extends the intermittent EnKF data assimilation method to a 4D continuous data assimilation (FDDA) scheme which is advantageous in terms of reducing the dynamic shocks commonly caused by the intermittent EnKF processes, alleviating the critical dependency on the background error covariance inflation, and augmenting an ability to practically and thus can effectively assimilate all observations that may be available at irregular locations and times;. The theoretical aspects, the key technical components, and the implementation challenges of 4D-REKF will be described. The test results with controlled experiments for a real weather case will be presented to demonstrate the strength of the 4D-REKF in comparison with the NCAR DART-EnKF, WRF-3DVAR, WRF-4DVAR, and the traditional nudging-based data assimilation systems.

34 - Inverse estimation of urban-scale CO emissions: assimilating in-situ observation with ensemble Kalman filter

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Jiang Zhu, Zifa Wang, Ming Wang, Jie Li, Min Shao

*A sequential emission inversion scheme (SEIS) is established based on ensemble Kalman filter to identify possible biases in emission inventory. It updates a priori emission inventory through assimilating high-temporal resolution observations, and takes into account model errors with perturbing key uncertainties sources. Furthermore, initial conditions of pollutants are optimized along with emission inversion for the purposes of constraining the error growth of simulated pollutant concentrations and reducing the influence of other uncertainty sources on emission inversion. The SEIS has been employed to identify possible deficiencies in the CO emissions inventory over Beijing and its surrounding areas. Surface CO observations over these areas during the summer season in 2010 are hourly assimilated into Nested Air Quality Prediction Model System (NAQPMS) and the Regional Emission inventory in Asia (REAS) as the priori emission inventory is updated. The results show that the CO emissions over these areas are underestimated by REAS especially at the cities of Tangshan and Baoding. In our inverse estimation, the CO emission rates in the summer of 2010 is 4105 (1.5*REAS), 3753 (1.8*REAS), 3170 (2.2*REAS), 4078 (2.5*REAS) Gg/year for Beijing, Tianjin, Tangshan and Baoding respectively. The inverted emission inventory is evaluated by independent observations and independent forecast experiment. The distribution of inverse CO emission rates is quite similar to that of satellite observed CO column. On the other hand, the RMSE of CO simulation with inverse emissions is reduced by 51% at assimilated sites and 30% at validated sites in comparison with those simulated through using REAS. The biases decrease from -0.53ppm to -0.19ppm at assimilation sites and from -0.48ppm to -0.25ppm at validation sites. Overall, findings from the current study show that the SEIS can be powerful tool for identifying possible deficiencies of the emission inventory. It also validates the speculations raised by previous studies that CO emission rates over Beijing and its surrounding areas in REAS and other inventories with similar CO emission level are underestimated.*
Keywords CO emission, inverse estimation, ensemble Kalman filter.

35 - Assimilation of Screen-Level Observations in the Canadian Land Data Assimilation System

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Marco L. Carrera, Sarah Dyck, Nathalie Gauthier, Maria Abrahamowicz, Stéphane Bélair

In an effort to improve the initial conditions of the land surface in its suite of operational models, Environment Canada is developing the Canadian Land Data Assimilation System (CaLDAS). While CaLDAS can ingest space-based observations, the focus of this talk will be on the assimilation of screen-level observations of near surface air temperature and humidity for the production of soil moisture and surface temperature analyses. CaLDAS is built upon the Ensemble Kalman Filter technique and perturbations of precipitation, radiation and temperature forcings are used to

generate spread within the ensemble. The objective of the project is the operational implementation of CaLDAS within the framework of the Canadian Global Deterministic Prediction System. Pre-implementation tests have been conducted for the year 2008-2009 on a 33-km latitude-longitude grid and, more recently, for the year 2011 on a 15-km Yin-Yang grid. Surface analyses have been generated for series of fifty summer and winter cases and their impact on numerical weather prediction will be shown using objective evaluation based on upper air and surface observations.

36 - Optimization of boundary conditions of a North Western Mediterranean coastal zone using HF radar measurements

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Anne MOLCARD, Philippe FORGET, Alexander BARTH

Correction of open boundary conditions (OBC) are attempted to improve surface velocity fields by assimilating HF radar velocities in a North Western Mediterranean (NWM) sea model nested in a large scale model providing East and South OBC.
A method based on HF radar velocities assimilation using an Ensemble Kalman Filter (EnKF) to derive the optimal wind forcing had already been validated. The objective of this work is to implement this method to the OBC correction. An ensemble simulation of the NWM sea model is carried out under different OBC to estimate model error covariance and covariance between surface currents and OBC. We evaluate the ability to correct the oceanic forcings and to improve the surface current using a distant HF radar system.
The method is assessed using twin experiments and a NWM sea model based on a Regional Ocean Model System (ROMS) configuration at 1/12°. We correct the eastern lateral boundary conditions given by the Mercator Ocean operational system (PSY2) which provides OBC and initial conditions. Simulated surface currents measurements are provided by an HF radar system close to Toulon. Final goal will be to apply the method to real HF radar measurements and high resolution (1/64°) NEMO-based model to study surface physical processes.

37 - Constraint of the recharge-discharge process of an intermediate ENSO model by sea level data assimilation

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Nadia AYOUB, Boris DEWITTE

The El Niño Southern Oscillation (ENSO) is a highly predictive phenomenon because it is partially driven by deterministic and low-order dynamics. The benefits of data assimilation on model simulations and forecasts may be envisaged with respect to this low-order dynamics. An intermediate ENSO model is forced by winds and constrained by sea level data from the SODA reanalysis, in order to initialize retrospective forecasts over the period 1958-2007. We use an Ensemble Kalman Filter assimilation method, where model errors arise from the uncertainty in atmospheric variability. Focus is given to the correction of the so-called Tilt and WWV spatial modes, which are associated to the low-order recharge/discharge process of the equatorial thermocline. Both modes are accounted for by covariance of model errors, and the assimilation permits to correct the WWV mode which variability is too weak in the model. An additional experiment is considered where observations are made coarser and model constraint is therefore minimised to the Tilt and WWV modes. This leads overall to similar results in terms of ENSO simulation and forecast, highlighting the essential role of low-order dynamics.

38 - Application of EnKF for the mesoscale forecast of a severe weather event in the western

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The western Mediterranean is a region climatologically prone for the development of high impact weather events. The prediction of such events is a great challenge for current operational offices due to the fundamental imbalance between degrees of freedom in the forecasting system (i.e. high spatial resolution) and the operationally available atmospheric information in the area (i.e. very low density of in-situ observations over the sea). We assess the value of an Ensemble Kalman Filter for the initialization of a mesoscale ensemble prediction system by comparing different configurations, including the basic downscaling from the operational ECMWF EPS predictions. The results from these experiments are expected to be transferred to the field within the HyMeX program context.
Results suggest that the use of EnKF is significantly benefiting the accuracy of the probabilistic predictions as the filter transfers information from over land towards maritime areas. The particular effects of this process are discussed

39 -A Dual Ensemble Kalman Filter Strategy for Data Assimilation into a Coupled Subsurface Contaminant Transport Model

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Predicting contaminant evolution in geologic aquifers requires coupling a subsurface flow model with a contaminant transport model. Assuming perfect flow model, one can directly apply an ensemble Kalman

40 - Simultaneous assimilation of meteorology and CO2 observations with EnKF in NCAR carbonclimate model

Junjie liu1
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CO2 concentration has been increased from 280 ppm in preindustrial period to the current ~395ppm, which is the primary cause of current climate change. The increase of CO2 observations from satellites, such as AIRS, GOSAT, OCO-2 (plan to launch 2014), provides an opportunity to monitor the change of CO2 and improve our understanding of the carbon cycle in a finer temporal and spatial scale. In this study, we will present an application of Ensemble Kalman filter in generating 6-hourly CO2 reanalysis by assimilating CO2 and meteorology observations simultaneously in NCAR carbon-climate model. The ensemble CO2 reanalysis could be used in evaluating transport model and CO2 retrieval. By assimilating meteorology observations along with CO2 with EnKF, the estimated CO2 uncertainty includes the impact of uncertainty in meteorology on CO2 fields. Liu et al. (2012) shows that assimilating AIRS CO2 observations improve the quality of CO2 concentrations when verified against aircraft observations. Based on Liu et al. (2012), we will further assimilate surface flask observations and GOSAT CO2 observations. We will show the quality of CO2 reanalysis when validated against independent CO2 observations, and analyze the relationship between CO2 analysis fields and major circulation, such as Madden Julian Oscillation. At last, we will briefly discuss the application of EnKF on surface CO2 flux forcing estimation using OSSE.

41 - Applying the Local Ensemble Transform Kalman Filter to the Nonhydrostatic Icosahedral Atmospheric Model (NICAM)

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Hiroshi L. Tanaka

In this study, we apply the local ensemble transform Kalman filter (LETKF) to the Non-hydrostatic Icosahedral Atmospheric Model (NICAM) to develop the NICAM-LETKF. In addition, an algorithm to adaptively estimate the inflation parameter and the observational errors is introduced to the LETKF. The feasibility and stability of the NICAM-LETKF are investigated under the perfect model scenario.
According to the results, we confirm that the converged analysis errors of the NICAM-LETKF are smaller than the observational errors, and the magnitude and distribution of the root mean square errors (RMSEs) are comparable to those of the ensemble spreads. In our experiments, we find that the inflation parameter is optimally tuned and the observational errors are close to the true value.
It is concluded that the NICAM-LETKF works appropriately and stably under the perfect model scenario even if the inflation parameter and the observational errors are adaptively estimated within the LETKF.

42 - Extracting maximum information from satellite observations using an ensemble-based data assimilation method

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Given the high degree of accuracy afforded by modern and future satellite instruments such as MSG SEVIRI, GOES-R Advanced Baseline Imager (ABI) and Global Lightning Mapper (GLM), the reliability of direct satellite radiance assimilation no longer depends on instrument calibration and noise as much as on the choice of assimilation method, forward model and spectral bands. In this study the Maximum Likelihood Ensemble Filter (MLEF) is applied to NOAA operational Hurricane WRF (HWRF) system to directly assimilate satellite radiance observations in TC inner core in an effort to estimate information content of satellite observations and explore optimal combination of satellite data. The system components also include the forward components of the Gridpoint Statistical Interpolation (GSI) and the Community Radiative Transfer Model (CRTM).
A priority in our presentation will be given to assimilation of all-sky AMSU-A radiances, as well as MSG SEVIRI channel 9 radiances, in HWRF inner domain. We will examine the performance of MLEF-HWRF verified against observations, then we focus on quantifying an entropy-based definition of information content with respect to different combination of channels and instruments. Using the channels on the AMSU-A as an example, the results show that over an oceanic background and for non-scattering clouds, the combination of conservative "temperature sounding" channels in concert with window channels provides the optimal channel combination within the scope of our study. With an eye toward developing a coherent representation, the method may be developed into a suitable multi-channel/multi-instrument methodology to provide the means of establishing a common framework for satellite observation assimilation in TC inner core and other severe weather systems.

43 - Multi-variate assimilation of remote sensing and in-situ data on a catchment scale.

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Henrik Madsen

It remains a crucial challenge to adequately estimate environmental conditions at the land surface in terms of both energy fluxes and hydrological conditions. With this aim, a multi-variate hydrological data assimilation system is development to assimilate in-situ and remote sensed data in the MIKE SHE modelling system - coupled to a Soil-Vegetation-Atmosphere Transfer (SVAT) model. The system assimilates satellite estimates of Land Surface Temperature (LST) from the

Meteosat Second Generation (MSG) satellite, Soil Surface Moisture (SSM) from MODIS AMSR-E as well as in situ hydraulic head.
A deterministic ensemble based Kalman filter algorithm using covariance localization of the in situ head observations is explored to minimize the number ensembles needed and to avoid spurious error correlations. Special emphasis is placed to the description of uncertainty and bias in the model and measurements, with focus in developing a bias aware ensemble based Kalman Filter.

44 - Ensemble Kalman Filter data assimilation in global MPAS/DART
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Chris Snyder

The Model for Prediction Across Scales (MPAS) is a global non-hydrostatic numerical atmospheric model based on unstructured centroidal Voronoi meshes that allow both uniform and variable resolutions. It has a great potential to produce high-resolution forecasts over regionally-refined areas since the centroidal Voronoi meshes feature smooth transitions between regions of different spatial resolutions which ameliorate many problems associated with tradional grid nesting methods.
Recently we established an interface between the MPAS and the Data Assimilation Research Testbed (DART) system, and successfully completed the Observation System Simulation Experiments (OSSE) in the analysis/forecast cycling mode. Based on the simulation study, we will discuss about the issues specific to the MPAS grid meshes such as smoothing effect in the interpolation and the update of horizontal wind fields, and show their impact on the Enensemble Kalman Filter (EnKF) analysis and the following short-range forecast.
In the real data application, we cycled one month of August 2008 assimilating conventional sounding, aircraft data as well as satellite winds and GPS radio occultation refractivities, and compared to the same EnKF cycling experiment using another global model - Community Atmosphere Model (CAM) at NCAR.

Session 6. *Ensemble Variational Assimilation*

45 - Representing ensemble covariances with a diffusion operator
Anthony Weaver: CERFACS – France. weaver@cerfacs.fr
Andrea Piacentini, CERFACS

This study describes how covariance information from an ensemble can be combined with a covariance model based on a diffusion operator. The resulting covariances are localized and, in general, inhomogeneous and anisotropic. The estimation problem involves determining, for each control variable, the local variance and local aspect tensor of the covariance function. The cross-covariances between control variables are assumed to be negligible, which can be approximately achieved through an appropriate variable transformation. The aspect tensor determines the scale response of the covariance function and is related to the diffusion tensor. Under the assumption of homogeneous correlations, the kernels of an implicitly-formulated diffusion operator belong to the Matern family.
The diffusion operator can be employed with background-error covariance models in variational assimilation. Application of the covariance model in an idealized framework and to a global ocean variational assimilation system will be presented.

Tuesday 13 November

46 - Session 7. (Quasi-)Operational Ensemble Prediction Systems

A stochastic dynamics method for ensemble seasonal forecasts with the CNRM-CM5.1 GCM
Lauriane Batté: CNRM-GAME, Météo-France
Michel Déqué (CNRM-GAME, Météo-France)

Ensemble seasonal forecasts using coupled global climate models (GCM) often suffer from insufficient spread and systematic errors. A new stochastic method we call stochastic dynamics (Batté and Déqué, 2012) addresses both issues at a time, by including additive stochastic perturbations in the atmospheric component ARPEGE-Climat of the CNRM-CM5.1 GCM, as random corrections of initial tendency error estimates. These estimates are first calculated following Guldberg et al. 2005 by nudging the atmospheric model prognostic variables temperature, specific humidity and stream-function towards ERA-Interim over a 1979-2010 hind-cast period for the November to February season (NDJF) in a coupled run. In seasonal forecast mode, each ensemble member is perturbed initially and during the run with error corrections from an appropriate population derived from the nudged run.
The random method significantly improves deterministic scores for 500-hPa geopotential height forecasts over the Northern Hemisphere extra-tropics (NH Z500) and increases the ensemble spread with respect to a reference ensemble, whereas the mean bias is reduced. An optimal method (drawing the error corrections within the current month of the hind-cast period) reaches correlation scores of over 0.6 with respect to ERA-Interim for NH Z500 anomalies and the North Atlantic Oscillation index. These promising scores are seen as an upper limit to forecast skill using the stochastic dynamics method, since the optimal method cannot be implemented in forecast mode. They lead us to investigate several possible classification criteria on the correction population in order to further improve seasonal forecasts over the region by choosing state-dependent corrections during the run.

47 - Study of the impact of combined TMI-PR retrieved rainy observations in regional weather forecast models in an ensemble Bayesian framework.

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Deepak Subramani,K. Srinivasa Ramanujam,C. Balaji.

This study mainly focuses on the impact of the vertical rain structure on regional weather forecast models using ensemble based data assimilation technique in a Bayesian framework. The study has been conducted to improve the track prediction of tropical cyclones that originate in the north Indian Ocean region. For this purpose, the tropical cyclone Jal has been analysed by the community mesoscale weather model, Weather Research and Forecasting (WRF), which takes the initial and boundary conditions from National Center of Environmental Prediction (NCEP) global forecast system (GFS) data. The study consists of single domain bounded between 76 E – 94 E and 6 N – 22 N, with a horizontal resolution of 6 km. Jal was a category 1 cyclone that originated in the warm Bay of Bengal waters on 4th Nov 2010 and made its landfall after 4 days near Chennai. Initial conditions corresponding to 00 UTC on 6th Nov have been considered, as the system attained category 1. Based on this data, the ensembles of prognostic variables such as potential temperature, perturbation geopotential, meridional and zonal velocities and total water vapour are generated by the Empirical Orthogonal function (EOF) technique. An over pass of the Tropical Rainfall Measuring Mission (TRMM) satellite occurred on 06th NOV 0730 UTC over the system and the in-house combined TMI-PR retrieved vertical rain structure namely the cloud water, cloud ice, precipitation water and precipitation ice are used as observation data. Each ensemble is input as a possible initial condition to the WRF model which was marched in time till 06th NOV 0730 UTC. The above mentioned hydrometers from cloud water and rain water mixing ratios are then calculated for all the ensembles. The Bayesian filter framework technique is then used to determine the probability between ensembles by comparing with TRMM observations. Based on the posterior

probability density function, the initial condition in 06 00 UTC has been corrected using a linear weighted average! of initial ensembles for the all prognostic variables. The model has been run up to 08th Nov 06 UTC and the results are then compared with observations. The model simulated track and maximum sustainable wind speed are compared with the Joint Typhoon Warning Center (JTWC) observations. Both the cyclone track and sustainable wind speed give better results than control run up to first 24 hours forecast, after which it follows the same pattern of control run. It may be concluded that the corrected initial condition has more impact in the initial 24 hours forecast after which the boundary conditions from the GFS exert more influence on the simulations. An ensemble independence study was also conducted on the basis of which, an optimum of 25 ensembles is arrived at.

48 - The impact of initial condition perturbations in COSMO-DE-EPS under different synoptic scale forcing

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Christian Ku□hnlein, Christoph Gebhardt, Martin Weissmann, George Craig

T*he convection-permitting ensemble prediction system COSMO-DE-EPS is operational at Deutscher Wetterdienst since May 2012. The individual ensemble members are created by perturbing the lateral boundary conditions of the limited-area model to account for synoptic-scale uncertainty, and selected physics parameterisation schemes aiming at smaller-scale uncertainty. In addition, initial condition perturbations have been incorporated recently in a pragmatic approach consistent with the lateral boundary condition perturbations.*
Here, we investigate the influence of the initial condition perturbations on the EPS forecasts with a focus on the predicted precipitation. For this purpose, the pre-operational set-up of COSMO-DE-EPS is compared to the similar EPS but without initial conditions perturbations, for a 3.5-month period in spring/summer 2011.
The impact of the initial condition perturbations is studied under consideration of the prevailing regime of large-scale forcing using the concept of the convective adjustment time scale.

49 - Application of a developed hydrological ensemble model based on single numerical weather prediction in the Huaihe River.

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A hydrological ensemble model, based on single numerical weather predictions (NWP), was developed for hydrological forecast purpose of Huaihe River in China. The incorporation of numerical weather predictions into hydrological forecasting systems can increase forecast lead times from a few hours to a few days. A single NWP precipitation, however, is insufficient as it involves considerable non-predictable uncertainties. Reliable and skillful precipitation ensemble forecasts are necessary for hydrological ensemble forecasting. A probability forecast model based on conditional meta-Gaussian distribution is presented to construct ensemble forecasts from single-value forecasts of precipitation in the Huaihe River of China. The distribution is modelled as a mixed-type in which the relationship between the positive observed precipitation and positive forecast precipitation is assumed to be bivariate meta-Gaussian. We also describe and comparatively evaluate the producing ensemble forecast precipitation with the root mean square error (RMSE) and Brier Skill Score. The Xinanjiang model was used for hydrological rainfall-run-off modelling. The upper reaches of the Huaihe River above Wangjiaba station in China was taken

as the test catchment. The developed hydrological ensemble model was applied to forecast 12 representative hydrological events of the test case from 1981 to 2003.The results show that, overall, the developed hydrological ensemble model driven by ensemble precipitation can capture observed hydrological process better than that driven by single numerical weather predictions in the test case.

Keywords: hydrological ensemble forecast, Ensemble precipitation, probability QPF， Bivariate meta-Gaussian distribution, the Xinanjiang model, Huaihe River

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50 - Convective scale ensemble at the Met Office, Part I: Probabilities, adaptive post-processing and impact of ensemble size

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Giovanni Leoncini (Met Office)

The UK Met Office is now routinely running a 12-member kilometre-scale "storm-permitting" NWP ensemble forecast system (MOGREPS-UK) with a focus on the prediction of localised high-impact weather such as severe convective storms out to 36 hours ahead. The model has a domain covering the UK with a grid spacing of 2.2 km.
This presentation will firstly discuss the motivation behind the set up of this ensemble and describe some of its characteristics. The objective is to provide probabilistic forecasts of local weather at scales that are inherently unpredictable with a deterministic kilometre-scale model. However, a 12 member ensemble is not sufficiently large to adequately cover the uncertainty at those scales using conventional tools. This means that the ensemble members need to be capable of representing the larger-scale (mesoscale) uncertainty, and additional, novel, spatial post processing is required for the unpredictable small scales to account for the relatively small ensemble size while yielding physically meaningful probabilities.
The second part of the presentation will describe a method for computing the spatial differences between ensemble members in order to adaptively determine the scales over which the spatial post–processing should be applied. The use of this approach can also provide insight into the impact of changing the size or resolution of the ensemble.

51 - Extended logistic regression with interaction terms applied to COSMO-DE-EPS precipitation forecasts

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C. Gebhardt, S. Theis, A. Röpnack, N. Schuhen, M. Buchhold

COSMO-DE-EPS is an ensemble prediction system at the convective scale developed at DWD. Based on the model COSMO-DE (2.8 km grid size), 20 members are generated including variations in boundary conditions, physics parameterization and initial conditions. The forecasts cover Germany, have a lead time of 21 hours and follow a three-hourly update cycle. Probabilistic forecasts are derived from the ensemble using equal weighting of ensemble members.
Logistic regression is a standard calibration method which demonstrated to be well suited for post-processing of precipitation forecasts. Extended logistic regression allows to provide full probability distribution forecasts and then yields mutually consistent probabilities independently of the precipitation threshold. Interaction terms are introduced in the predictive equation to describe the interdependency between predictors.
Extended logistic regression with interaction terms is applied to COSMO-DE-EPS precipitation forecasts. Probabilistic forecasts assessment is performed for a summer period to show the benefit of the ensemble calibration approach.

52 - A probabilistic ensemble based wind forecasting system for the international airport Frankfurt/Main

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Nina Schuhen, Michael Buchhold

Wind conditions have significant impact on the air-traffic system even non-hazardous ones. Within the aviation research project iPort WiWi (innovative airPort adverse wind conditions) a probabilistic wind forecasting system for the international Frankfurt Airport is developed. The probabilistic forecasts are based on the COSMO-DE-EPS, the convection-permitting ensemble prediction system developed at DWD (German Meteorological Service). The COSMO-DE-EPS is running in operational mode since May 2012.
Besides the generation of calibrated ensemble based wind forecast products (e.g. exceedance probabilities or quantiles) a high priority is to develop costumer-oriented forecasting products as basis for proper decision making as the wind speed and direction is decisive for the runway in use. Thus, after assembling the customer requirements the wind forecast products have been designed and visualised accordingly. For this reason, the communication of the use of ensemble forecast products is an important part within this project. During a three month testing phase in summer 2012 the end user may evaluate the customized forecasting products for future operational use. The findings presented include a description of the development of the wind forecasting system as well as results and experiences from a three month testing phase.

53 - Towards the development of a convection-permitting ensemble based on the COSMO model over Italy

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Andrea Montani, Tiziana Paccagnella

Aiming at the development of a convection-permitting ensemble system based on the COSMO model over Italy, some aspects of ensemble design are currently being studied.
First, it has been investigated the influence of model perturbations run at high resolution (2.8km) on the probabilistic prediction of precipitation. The model is perturbed by applying random perturbations to a pre-selected set of the physics parameters. The impact of this perturbations on the forecasts has been studied by comparing the precipitation distributions, as forecasted by the model runs and as observed by both a gauge network and by radar.
Then, the impact of initial and boundary condition perturbations have been studies. At this stage of the work, initial condition perturbations are coming from the coarser resolution runs which drive the 2.8km model. At a later stage, initial condition perturbations obtained with a LETKF approach currently under development in the COSMO Consortium will be considered.
As for initial and boundary condition perturbations, two approaches were tested, nesting COSMO at 2.8 km on two different mesoscale ensembles run at 7km, which in turn receive boundaries from two global ensembles. The 7km COSMO-LEPS ensemble is a downscaling of the ECMWF EPS, where 16 EPS members are selected to drive 16 COSMO runs . The 7km COSMO-SREPS ensemble receives initial and boundary conditions through a multi-model approach, being driven by the operational runs of ECMWF, DWD and NCEP.
Results show the strong impact of initial and boundary conditions perturbations on the 2.8 km forecasts. In particular, analysing the precipitation distribution on different sub-domains, it is evident that this is highly dependent on the global model which is providing initial and boundary conditions to the 7-km run which in turns drive the 2.8km run. The relative impact of initial and boundary condition perturbations and of model perturbations at the different scales is also discussed.

54 - The US Navy's RELO Ensemble System and it's Application to Lagrangian Trajectory Prediction in the Gulf of Mexico.

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Clark Rowley, Charlie Barron, Gregg Jacobs and Paul Martin

The US Navy's RELO ensemble system with 32 members consists of an ocean model NCOM and NCODA 3D-Var DA system. A version of RELO with 3km resolution is run for the period of June - July 2012 for the Gulf of Mexico (GOM). It is shown that the ensemble mean is much more superior to the single deterministic forecast with the same resolution in terms of accuracy and skill. The extended forecast time (EFT) is introduced and computed to quantify the advantages of the ensemble mean forecasts over a single deterministic forecast. The ensemble spread is improved by perturbing the vertical and horizontal mixing parameters with various statistics in the NCOM.
The advantages of using RELO ensemble over the single forecast in predicting the Lagrangian trajectories in GOM are demonstrated. The impact of the ensemble spread on Lagrangian prediction is studied. In order to further improve RELO's reliability and forecasting skill, we plan to develop more comprehensive physical parameterization schemes to account for more model related uncertainties in NCOM.

55 - Early-warning products for extreme weather events using operational medium-range ensemble forecasts

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Tetsuo NAKAZAWA (WMO)

Extreme weather events, heat wave, flood, heavy rainfall, cyclone, MJO, atmospheric blocking, etc, have socio-economic impacts on humanity. An accurate prediction of extreme weather events is important for the benefit of society, the economy and the environment. In this talk, a prototype of ensemble-based early-warning products for extreme weather events, available at http://tparc.mri-jma.go.jp/TIGGE/index.html*, are introduced. The early-warning products are based on operational medium-range ensemble forecasts from four of the leading global NWP centres: ECMWF, JMA, UK Met Office and NCEP. The forecast data have been extracted from the TIGGE database (see* http://tigge.ecmwf.int*); these TIGGE data are available with a 2-day delay as part of the THORPEX research programme. The forecast probability of occurrence of extreme weather event, heavy rainfall, strong wind, and high/low temperatures, is measured by the fraction of ensemble members that predict higher or lower values than each model's climatological percentile (e.g. 99th percentile) to ensemble size. In this method, products by multi-centre grand ensemble consisting of these centres also can be considered. This talk shows some examples of products for extreme weather events: the Pakistan floods in July 2010, tropical cyclone Yasi in February 2011, and the South Africa flash flood/snow in June 2011. The early-warning products based on a simple method can highlight the risks of extreme weather events in advance.*

56 - Current work on COSMO-DE-EPS

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A convection permitting ensemble prediction system (EPS) based on the deterministic COSMO-DE is being developed by the Deutscher Wetterdienst (DWD) to consider the forecast uncertainties on the short-range scales. Since 22th May 2012, the COSMO-DE-EPS is operation at the DWD with 20 members. For the further development of the short-range EPS in addition to the post-processing, an increase of the ensemble size up to 40 member using additional initial and boundary conditions from the COSMO-LEPS is under investigation.
Furthermore, additional variations of the physic will be investigated and adopted into the ensemble e.g. variations of the minimal diffusion coefficient for heat/momentum. First results of the 40 member EPS and of additional physics variations will be shown.

57 - Improvement of the Initial Perturbation Method toward Pre-operation of the Mesoscale Ensemble Prediction System at the JMA

Kosuke Ono: Japan meteorological agency – Japan

The Japan Meteorological Agency (JMA) has a plan to pre-operate the Mesoscale Ensemble Prediction System (MEPS) with a grid spacing of 10 km in FY2013 for the provision of probabilistic information and multi-scenarios to the operational mesoscale NWP. With the update of the super computer system at the JMA in June 2012, we started to develop the MEPS with a configuration closer to its pre-operation.

In the MEPS, initial and lateral boundary perturbations are generated by blended mesoscale and global singular vectors (SVs) aiming to capture the uncertainty of initial and lateral boundary values caused by meteorological phenomena of synoptic scale and mesoscale. These SVs are calculated by the tangent linear and adjoint models based on the JMA global spectral model and the JMA non-hydrostatic model. As characteristics of the SV method, each perturbation is locally calculated near a meteorological disturbance, which causes a large forecast error. These characteristics are useful for studies on error growth and sensitivity of a specific meteorological disturbance, and for ensemble forecasting targeted to a specific meteorological disturbance. However, such localized perturbations cannot reflect all types of uncertainty in the operational forecast region. Thus, the use of only SVs-derived perturbations is not enough for the pre-operation of the MEPS, which targets not only specific meteorological disturbances but also various uncertainty of the atmosphere.

In order to compensate for the localization of perturbations derived from SVs, the perturbations derived from a previous ensemble forecast (planned interval of initial time is 6 hours for the pre-operation) are used. In our investigation, it was found that low frequency modes of perturbation derived from the previous ensemble forecast grow linearly during the forecast period (36 hours), indicating that low frequency mode perturbations are expected to still grow in the next forecast period. Therefore, low frequency modes of perturbation from a previous ensemble forecast are available for generating complementary perturbations. Moreover, for avoidance of overlapping such perturbations with SVs, complementary perturbations are only used in an orthogonal complement of the space spanned by SVs. At the conference, we will show the details of the MEPS and the effectiveness of this complementary perturbation method.

58 - Calibrating 2m Temperature Forecast for the Regional Ensemble Prediction System at NNPC

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Min Wang,Chengdu University of Information

The ensemble prediction systems (EPSs) generally are subject to the systematic deficiencies, such as the forecast biases and under-dispersion. The non-homogeneous Gaussian regression (NGR) method has been developed to improve the spread-skill relationship of the EPSs for the continuous forecast variables. The NGR method is based on the multiple linear regression technique, and provides a Gaussian predictive probability density function (PDF) based on the ensemble mean and ensemble spread from the EPSs. In this study, the NGR approach is applied to calibrate the 2-m temperature forecasts from the regional EPS at National Numerical Predication Center (NNPC) of China Meteorological Administration, and the minimum continuous ranked probability score (CRPS) estimation is used to fit the regression coefficients of the calibrated PDF. The experiment results are evaluated using Talagrand histogram, the brier score, relative operating characteristic (ROC) area, and the CRPS. It can be found that compared with the raw ensemble output the NGR method can greatly improve the 2m temperature forecast, and the improvement is as follows: 1) the ensemble mean bias is reduced, and the ensemble spread is increased; 2) the L-shaped Talagrand histogram of the direct ensemble output has been greatly improved; 3) the probabilistic scores (the brier score, CRPS, area under ROC curves) all show the significant forecast skill improvement in the calibrated 2m temperature forecasts. The experiments also are performed to investigate the effect of the training length in the NGR method, and results show that calibrated results are

insensitive to the training length. Furthermore, the preliminary comparison between the time-decaying average bias correction method and NGR is performed, and the results show that the NGR method not only seems to have advantages for reducing ensemble mean bias and increasing ensemble spread, but also for improving the 2m temperature forecast skills in terms of probabilistic scores.

59 - Validating an Ensemble based Forecasting System of the North and Baltic Seas
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Quality of the forecast provided by the German Maritime and Hydrographyc Agency (BSH) for the North and Baltic Seas had been previously improved by assimilating satellite sea surface temperature (SST). We investigate possible further improvements using in situ observational temperature and salinity data: Marnet time-series and CTD measurements. To assimilate the data, the SEIK filter is implemented. The maximum Entropy approach is used as an additional criterion of the system performance.

Session 8. ***(Quasi-)Operational Assimilation Systems***

60 - The Kalman Filter Technical for Adjusting Numerical Weather Prediction Model to Improved Forecasting of Thai Meteorological Department
Kamol Promasakha na Sakolnakhon: Thai Meteorological Department (TMD), Thailand

The Kalman Filter (KF) technique has been used widely for applications meteorological in many organizes for adjusting ensemble forecast products to corrected forecast data output. The Numerical Weather Prediction (NWP) of Thai Meteorological Department (TMD) used this technical in a few years. The main objective of numerical weather prediction (NWP) give a precise estimation of the weather in which used a set of initial conditions input the Weather Forecast and Research analysis and forecast. The Kalman Filter technical used adjust the numerical weather prediction as the accumulate rainfall, the temperature and the relative humidity products to approach correctly analysis and forecast. The effectiveness of the Kalman Filter (KF) technical can adjust the numerical weather prediction model products of TMD and the finally the meteorologist used to guidance for forecasting in the regional area. The results showed some encouraging significant that KF may be used to improve the predictions of the accumulate rainfall, the temperature and humidity. Therefore, the Kalman Filter (KF) is a Numerical Weather Model implementation of prediction that is the classical Kalman Filter in which applicable NWP. Future more, the Kalman Filter will be applied improve another parameters in NWP.

Key words: Kalman Filter, Numerical Weather Prediction, NWP Verification

61 - Pseudo-coupled data assimilation and ensemble generation for intraseasonal prediction: impacts on forecast skill
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A.G. Marshall, Y. Yin, P. Okely, O. Alves, H. Hendon

The Bureau of Meteorology has recently developed the capability to make dynamical intraseasonal climate forecasts based on modifications to the coupled-model seasonal forecast system, POAMA (Predictive Ocean Atmosphere Model for Australia). The seasonal prediction version of POAMA was not designed for intra-seasonal forecasting and has deficiencies in this regard. Most notably, the growth of the ensemble spread in the first month of the forecasts in the seasonal system, generated primarily from perturbed ocean initial conditions, is too slow to be useful on intraseasonal time-scales. This deficiency has been addressed through enhancements to the ensemble generation and initialisation strategy. An innovation of the new forecast system is a

coupled-model breeding method which produces an ensemble of perturbed atmosphere and ocean states that can be used to initialise the forecasts. It will be shown that this new scheme impacts favourably on the intraseasonal forecast skill, as well as the seasonal-scale skill. In this first version of the initialisation strategy, the atmosphere and ocean data assimilation was done separately, with uncoupled models. A further enhancement to the initialisation strategy is currently being tested. This is a pseudo-coupled data assimilation system such that the data assimilation step is now performed with the coupled model. Assimilation into each component of the coupled model occurs separately, but the background states are evolved using the coupled model. This method is closely aligned with the ultimate goal of fully coupled assimilation. Initial results of the impact of this new system on forecast skill will be shown.

62 - Impact of a Hybrid Variational-Ensemble Data Assimilation System on the Performance of an ETKF-based EPS System

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Jelena Bojarova and Nils Gustafsson

One of the activities within the GLAMEPS [Grand Limited Area Model Ensemble Prediction System] project is to develop techniques for the specification of Initial Condition perturbations with as good properties as possible. One such technique is the ETKF [Ensemble Transform Kalman Filter] rescaling scheme, which has been developed within the HIRLAM project. In addition to being based on a different methodology compared to the techniques used for the first operational version of GLAMEPS, the ETKF perturbations are also produced internally within the limited area model. The theoretical foundation of the scheme as well as its practical implementation is presented in Bojarova et al. (2011).
Furthermore, a hybrid Variational-ETKF Data Assimilation (DA) scheme has been implemented into the HIRLAM forecasting system. The structures of the static forecast error covariance are merged with the flow-dependent structures of the HIRLAM ETKF perturbations, by means of the extended control variable method (Lorenc 2003). The produced analysis increments are weighted averages of the full-rank variational increments and the local in space linear combination of the rank-deficient ETKF perturbations. In general, the hybrid scheme assigns smaller weights to mass observations in comparison to those produced by the pure variational scheme, and, in its optimal settings, outperforms (slightly) the 3DVAR Variational Data assimilation scheme.
A set of real observation experiments (conventional observations and ATOVS satellite data) has been performed for a two month period in the winter of 2010-2011 where the ETKF technique has been used with and without the use of the hybrid Variational-ETKF data assimilation scheme. Results of a comparison of properties of the ETKF-based EPS system as a result of employing the two DA schemes will be presented as well as a comparison with the operational GLAMEPS system.

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63 - Performance of the reduced space (ensemble) 4Dvar technique with community models

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Reduced space four dimensional data assimilation (R4Dvar) is an efficient way to assimilate data without developing tangent linear and adjoint codes. The algorithm is based on interative minimization of the cost function in a sequence of low-dimensional subspaces, spanned by the leading EOFs of the ensembles derived from the model runs on each iteration. As it was shown

*before, the R4Dvar outperforms the conventional adjoint-based 4Dvar data assimilation technique in the case of assimilation into strongly non-linear models. We illustrate performance of the R4Dvar in a series of twin-data assimilation experiments into diverse community models (MIT GCM, WAM, Canadian Ice, etc) and discuss potential advantages of the new data assimilation approach.***Session 9. *Identification and Representation of Model Errors***

64 - A comparison of methods for estimating model uncertainty in the NCEP Global Ensemble Forecast System
Thomas Hamill: NOAA Earth System Research Lab, Physical Sciences Division, US.
Philip Pegion, Jeffrey S. Whitaker

Ensemble prediction methods must correctly simulate the forecast uncertainty due to both initial condition errors and model error to produce reliable forecasts. There are many competing methods for estimating model uncertainty, including stochastic perturbed tendencies (ECMWF), stochastic backscatter (UK Met Office, ECMWF, CMC), stochastic tendencies (NCEP), vorticity confinement (UK Met Office), and stochastically parameterizations (many institutions).
Using the NCEP Global Ensemble Forecast System (GEFS) , we attempt an intercomparison of these methods in order to determine which one, or which combination, are the most useful. The methods will be evaluated for their impact on probabilistic forecast scores for medium range predictions as well as their impact on improving the short-range forecast fit to observations in a global ensemble Kalman filter/variational hybrid system. High-impact weather events such as hurricane track predictions and heavy rainfall will also be evaluated.

65 - Parameter sensitivity tests for informing model error simulation methods in convective-scale ensembles
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Errors in forecasts originate from a number of sources: (i) the forecast's initial conditions, (ii) the boundary conditions and (iii) the model formulation, which all follow from and influence the data assimilation schemes used. Meso-to-convective-scale data assimilation and forecasting presents new challenges because at these scales model errors are thought to become dominant. The work presented here, part of the DIAMET (DIAbatic influences on Mesoscale structures in ExTratropical storms) project, is to investigate sources of model error that affect the forecast skill at convective scale. We present work on the effect of model error resulting from the parameterisation of unresolved processes (specifically microphysics and turbulent boundary layer processes). An experimental convection-permitting (1.5 km) version of the Met Office's 24-member Global and Regional Ensemble Prediction System (MOGREPS) has recently been developed. The 1.5km-EPS is run on a limited area domain over the southern UK with 1.5 km horizontal grid-length and 70 vertical levels. At 1.5-km resolution, in which no convection scheme is used, model error is introduced by "perturbing" parameters controlling the microphysics and turbulence schemes. Here we present the sensitivity studies carried out to determine the key parameters and their ranges.

66 - Stochastic physics scheme in the ensemble prediction system of Météo-France.
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Laurent Descamps, Philippe Arbogast

A stochastic physics scheme to represent model error in the operational ensemble prediction system of Météo-France is presented in this study. Over the past 20 years, more efforts have been given to the representation of errors arising from the initial condition production. The representation of the model error contribution is a more challenging task since the sources of this error are diverse and partially known. In this study, we have estimated model error variances by subtracting the predictability error variances from forecast error variances in spectral and physical space. Then, these estimated model error variances provide information for generating stochastic forcing

vorticity functions. The impact of the stochastic physics scheme is compared with that of the multiphysics approach currently used to represent model error in the operational ensemble prediction system of Météo-France.
Some preliminary results show that the implementation of the stochastic physics scheme improves significantly the reliability of a 35-member ensemble predictions (using only one physical parameterization). Moreover, over Europe, the ensemble predictions using the stochastic physics scheme can be as reliable as using the multiphysics approach. However, no significant impact is found in terms of resolution.

67 - Impact of Model-Error Representation on Ensemble Predictions in NWP
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K. Smith, So-Young Ha, C. Snyder

Model uncertainties can impact flow-dependent predictability and might be the leading contributor to unreliable ensemble forecasts.
Here we compare the impact of different model-error schemes on short-term ensemble predictions with the Weather Research and Forecasting (WRF) model: Two stochastic parameterizations (a stochastic kinetic-energy backscatter scheme and a stochastically perturbed physics-tendency scheme) aim to represent the effects of missing subgrid-scale fluctuations. Alternatively, a multi-parameterization scheme uses different physics-packages for each ensemble member.
All model-error schemes produce more reliable and more skillful ensemble forecasts. The structure of the spread in the various ensemble experiments is analyzed to determine to which degree the improvements are the result of a larger spread amplitude or better spatio-temporal correlations with the root-mean square error.

68 - Impact of a stochastic kinetic-energy backscatter scheme in data assimilation experiments with CAM-DART
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To study the impact of model-error representations on analyses produced by the the Data Assimilation Research Testbed (DART) for the ensemble Kalman filter, a stochastic kinetic-energy backscatter scheme was implemented into the Community Atmosphere Model (CAM).
The stochastic backscatter introduces more spread in temperature and wind forecasts and leads to a better agreement between ensemble spread and root mean square error of the ensemble mean.
The impact on the RMS error of prior and posterior will be quantified.

69 - Towards a Stochastic Parameterization in γ-scale HARMONIE EPS
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Spanish Meteorological Agency (AEMET) is member of HIRLAM consortia and is involved in GLAMEPS project participating in HarmonEPS in order to develop a future high resolution ensemble prediction system (EPS) based on HARMONIE NWP model.
One of the most challenging issues in the development of EPS at gamma-scale is how to take into account the model errors and uncertainties. This is especially true for the Very Short-Range of the simulations when the errors of the small scales growths faster than bigger scales until its saturation (Lorenz, 1969). Although this rapid non-linear growth of uncertainties is somehow intermittently due to its dependency on the meteorological situation. And it occurs in a three dimensional unbalanced flow with a rapid up-scale error propagation associated with the -5/3 energy spectrum at those scales.
Different approaches to deal with model error of gamma-scale EPS have been experimented. Some relevant examples are: a) Perturbing some relevant uncertain parameters in sub-grid

parameterizations (Gebhard et al, 2010) ; b) Using a combination of multi-model and multi-physics (Kong et al, 200); and c) Using a stochastic parameterization (Bouttier et al, 2012). Unfortunately all of these methods have turned out to be under-dispersive at the Very Short-Range. Perhaps this could means that growth of the model error close to gamma-scale has not been represented properly. Related to this it has been stated that for cloud-resolving scales the EPS methodologies of synoptic-scales could appear less promising (Hohenegger and Schär, 2007).
Anyway stochastic parameterizations provide a methodology for representing model uncertainty in EPS, and have proved, at least at alfa and beta scales, to have the ability to improve the EPSs performance. So an explicit stochastic perturbation to the net effect of parameterized physical processes, called Stochastically Perturbed Parameterization Tendencies scheme (SPPT), have been included successfully for years in ECMWF EPS forecast.
The aim of the present study is to present the first steps to implement on HARMONIE EPS a SPPT scheme based on the operational one in ECMWF EPS.
Two approaches have been developed with multiplicative-noise perturbing HARMONIE physics tendencies applied: 1) Independently to each single-column grid-point, and 2) With spatial and temporal correlations, that is the common SPPT.
Firstly both model perturbations have been verified whether degrade the deterministic forecast quality. The rationale behind is that any ensemble member has to be a plausible physical forecast, and though because perturbations some degradation is could expected, not so much is desirable. Interestingly some perturbed deterministic forecast on quite convective situations are not degraded, in fact they performance is even better.Secondly for both perturbations a small EPS have been integrated showing an improvement of EPS performance with both methods, but they share the common feature of under-dispersion in the Very Short-Range. Finally it is speculated how extremely high non-linear error growth rates close at gamma scale could be dealt properly in the foreseeable future with stochastic parameterizations.

Session 10. *Further Developments*

70 - Sampling properties and spatial filtering of ensemble background-error length-scales
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Olivier Pannekoucke

Ensemble data assimilation is now a common method to estimate flow-dependent background-error statistics. This technique can be used to directly estimate the full covariance matrix, as it is the case in ensemble Kalman filters. Ensemble systems are also beneficial to variational data assimilation since they can provide estimates of variances and parameters of the correlation model.
In particular, correlation length-scales (Daley 1991), which describe the curvature of the correlation function near the origin, can be calculated from an ensemble of forecasts. On the one hand, estimated length-scales are a common diagnosis of existing correlation functions. On the other hand, they can be used to calibrate a correlation model, based on a diffusion operator or recursive filters for instance.
However, the small size of ensemble systems in realistic applications (namely between 5 and 100 members) introduces a relatively large sampling noise on the estimated parameters. Following early works from Pannekoucke et al. (2008), we will first give some insight into the statistical properties of the noise associated with the estimated correlation length-scales. Moreover, local spatial averaging has proved efficient for reducing the sampling noise in ensemble-based variances and covariances (Berre and Desroziers, 2010). We will discuss the tuning and the efficiency of such filtering techniques in the case of estimated length-scales.

71 - A New Structure of Error Covariance Matrices and Their Adaptive Estimation in EnKF Assimilation

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Guocan Wu, Liqun Wang

Correct estimation of the forecast and observational error covariance matrices is crucial for the accuracy of a data assimilation algorithm. In this paper, we propose a new structure of the forecast error covariance matrix to account for limited ensemble size and model error. An adaptive procedure combined with a second-order least squares method is applied to estimate the inflated forecast and adjusted observational error covariance matrices.
The proposed estimation methods and new structure of the forecast error covariance matrix are tested on the well-known Lorenz-96 model, which is associated with spatially correlated observational systems. Our experiments show that the new structure of the forecast error covariance matrix and the adaptive estimation procedure lead to improvement of the assimilation results.

72 - Use of ensemble assimilation to estimate climatological and flow-dependent background error covariances for a convective-scale data assimilation system : AROME-France
Pierre Brousseau: Météo-France,CNRM-GAME – France. pierre.brousseau@meteo.fr
Loïk Berre, Gérald Desroziers And François Bouttier

AROME-France is a convective-scale Numerical Weather Prediction system running operationally at Météeo-France since the end of 2008. It uses a 3D-Var assimilation scheme in order to determine its initial conditions.
Static background error covariances are calculated for the 3D-Var using an AROME-France ensemble assimilation. These covariances, representative of the small scales of the model, allow a better use of observed information for small scales, which improves system performance.
The ensemble assimilation is also used to estimate background error covariances of the day. A 6-member ensemble is shown to provide robust covariance estimates in the context of the considered homogeneous covariance formulation. There is significant day-to-day variability in the variances, auto-correlations, and cross-correlations of background errors. This variability is linked to the meteorological conditions over the AROME-France model domain.
Thus, the data assimilation system uses observations according to variations of atmospheric state characteristics, predictability in particular. The benefits of using flow-dependent background error covariances, instead of static ones, are shown using assimilation diagnostics and measures of forecast performance.

73 - Estimating deformations of random processes for correlation modelling in data assimilation: comparison with the semi-geostrophic transform.
Raphaël Legrand: CNRM-GAME, Météo-France and CNRS – FRANCE.
Yann Michel, CNRM-GAME, Météo-France and CNRS

Data assimilation makes extensive use of covariance models in order to describe the statistical structure of errors that are present in the observations, in short term forecasts, and in the numerical model. Building on work in the computer vision community, we introduce the « shape from texture »' approach for the modelling of covariances and correlations in data assimilation with large dimensions. In this framework, the covariance model is obtained as the deformation, or coordinate transform, of a stationary covariance model. The deformation is objectively estimated from the data from a wavelet analysis.
In the past, a transform based on semi-geostrophy theory has also been proposed to build flow-dependent correlations. The goal of this work is to compare the two approaches with objective measures of performance. We use indexes of anisotropy and stationarity to quantify the effect of both deformations on an ensemble representing the error correlations of the day. The objective, statistical-based deformation seems to outperform the deformation based on semi-geostrophy.

74 - Adaptative denoising of ensemble-based background error variance maps.
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Thibaut Montmerle, Loik Berre and Yann Michel

It is now well established that the background error covariance matrix - the "B matrix", a key element in VAR systems - should be flow-dependent to get an optimal assimilation of observations in operational NWP systems. Currently, the computation of an "error of the day" rely mostly on ensemble forecasts, from which statistical properties of the forecast error can be drawn. Due to the high computational cost of current NWP models, running an ensemble is a very expensive task, although it can be easily parallelised. Consequently, only small ensembles can be operationally run, introducing significant sampling errors in the calculation of forecast error statistics.
Our work focused on the regional model AROME, operational at Meteo-France (2.5 km resolution, non-hydrostatic, 3h-assimilation cycle), for which we would like to use flow-dependent unbalanced errors variance maps (i.e. after removal of multivariate and vertical covariances), instead of an averaged climatological value. We are expecting an improvement of observations assimilation, especially at meso-scale (e.g. radar data).
A first, we try to modulate climatological unbalanced background error variances by interpolated variance maps coming from the operational ensemble assimilation system at global scale AEARP. No improvements were obtained, probably because of the strongly different variance structures displayed by AROME. We are thus working on the processing of variance maps extracted from a small ensemble (less than 10 members). While it may looks like a classical image denoising exercise, the sampling noise arising here is very different from a sensor or a transmission noise. Sampling theory has shown that the sampling noise of an estimated variance map is always unstationary, making spectral filtering algorithms sub-optimal, though rather efficient. We are therefore investigating adaptative algorithms that would not rely on a stationarity assumption, either for the signal or for the noise. Various algorithms (Lee filtering, wavelet thresholding, anisotropic diffusion, etc...) will be presented as well as their relevance for the denoising of ensemble-based variance maps.

75 - Accounting for Skewness in Ensemble Data Assimilation
Daniel Hodyss: Naval Research Laboratory – USA.

I will discuss a new framework for understanding how a non-normal probability density function (pdf) may affect a state estimate and how one might usefully exploit the non-normal properties of the pdf when constructing a state estimate. A Bayesian framework is constructed that leads naturally to an expansion of the expected forecast error in a polynomial series consisting of powers of the innovation vector. This polynomial expansion in the innovation reveals a new view of the geometric nature of the state estimation problem. Among other things a direct relationship is shown between the degree to which the state estimate varies with the innovation and the moments of the distribution.
A practical data assimilation algorithm will also be presented that explicitly accounts for skewness in the prior distribution. The algorithm operates as a global-solve (all observations are considered at once) using a conjugate-gradient technique and Schur/Hadamard (element-wise) localization, and as a general rule is only a factor of four more expensive than the traditional ensemble Kalman filter. The central feature of this technique is the squaring of the innovation and the ensemble perturbations so as to create an extended state-space that accounts for the second, third and fourth moments of the prior distribution. This new technique is illustrated in a simple scalar system as well as in a Boussinesq model of O(10^4) variables configured to simulate non-linearly evolving Kelvin-Helmholtz waves in shear flow. It is shown that ensemble sizes of at least 100 members is needed to adequately resolve the third and fourth moments required for the algorithm. For ensembles of this size it is shown that this new technique is superior to a state-of-the-art Ensemble Kalman Filter in situations with significant skewness, otherwise the new algorithm reduces to the performance of the Ensemble Kalman Filter.

76 - Evaluating the potential impact of lightning data assimilation utilizing hybrid variational ensemble methods

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A hybrid data assimilation algorithm seeking a non-linear solution which employs an iterative minimization of a cost function is employed to assimilate a non-linear observation operator (lightning) into a numerical weather prediction model. The potential impact of lightning data assimilation to correct the intensity and location of deep moist convection, which may lead to the development of severe weather (e.g. thunderstorms and tornadoes) is evaluated. The Maximum Likelihood Ensemble Filter (MLEF), interfaced with the Non-hydrostatic Mesoscale Model core of the Weather Research and Forecasting system (WRF-NMM) and with the inclusion of lightning flash rate as a forward observation operator is utilized to assimilate World Wide Lightning Location Network (WWLLN) lightning data. Regional data assimilation experiments are conducted for a severe tornado outbreak across the south-eastern United States on April 25-28, 2011. Preliminary results indicate the utility of lightning data assimilation in the analysis and improvement of six-hour WRF-NMM forecasts. Results that highlight the differences with and without the assimilation lightning data will be presented.

77 - Sampling error damping method for a cloud-resolving model based on ensemble forecast error analysis

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In ensemble-based assimilation schemes for Cloud-Resolving Models (CRMs), sampling error is serious, in particular, for precipitation-related variables (precipitation rate, vertical wind speed) because they are confined in rainy areas. While previous studies proposed several sampling error damping ideas (spatial localization, spectral localization, wavelet diagonal assumption, variable localization), there has been few studies that have discussed their applicability to CRMs.
The purpose of the present study is twofold:
1) We examine whether CRM ensemble forecast error satisfies the presumptions of the above sampling error damping ideas.
2) Based on the applicable damping ideas, we develop the sampling error damping method that calculates plausible forecast error correlation for CRM variables.
For the first purpose, we analyzed CRM ensemble forecast error for three meteorological cases (Typhoon, extra-tropical low, Baiu). The results show:
1) Horizontal forecast error auto-correlation patters were narrow for the precipitation-related variables (~ 15 km), while they changed (160 km ~ 40 km) in terms of precipitation rate for other variables. Accordingly, we cannot apply simple spatial localization with a common localization scale for all CRM variables.
2) When we transformed the horizontal forecast error auto-correlation into wave space, the correlation matrix became diagonal for the precipitation-related variables. For other variables, the matrix had negligible values for off-diagonal elements with large wave number differences. Accordingly, the presumption of the spectral localization was satisfied.
3) Cross-correlation between CRM variables changed substantially in terms of precipitation rate. Accordingly, we cannot assume the same sets of unrelated variables in the variable localization for different precipitation ranges.
For the second purpose, we developed the sampling error damping method based on the spectral localization. In this method, we approximated the forecast error correlation using neighboring ensemble (NE) members of the target points (5x5 grids in the neighboring area). We applied this method to the above meteorological cases to find out that this method had little deformation of the ensemble forecast correlation at points with negligible sampling error, and that this method damped the sampling error of the precipitation-related variables at points where large sampling error was expected because of small number of rainy members.

78 - Flow dependent predictability of the North Atlantic jet

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The North-Atlantic jet is a major component of the large scale flow governing the weather in north-western Europe. Here we examine the evidence for flow-dependent variations in jet predictability. The jet state is represented in a two-dimensional plane by the leading EOFs derived from ERA40. The estimated probability distribution function (pdf) in this reduced space, is uni-modal but distorted. The extent to which "interesting" structure in the pdf can be associated with variations in persistence with location is examined.
Ensemble predictions of the jet are obtained using data from the TIGGE archive. Variations in the rate of divergence of ensemble members with forecast validity time are shown to be consistent between forecasts of different lead time and from different centres, indicating strong flow dependence in predictability. The extent to which such flow dependence relates to jet state is examined.

79 - AEMET-SREPS: past, present and future

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The Spanish meteorological Agency (AEMET) Short-Range Ensemble Prediciton System (AEMET-SREPS), was an European pioneer last decade as a multi-model multi-boundaries LAMEPS. Deterministic models are currently going down through convective scales, and ensembles should follow. However, new predictability issues arise at these scales and the design of an EPS on the gamma-mesoscale needs further insights. Current research lines include Stochastic Perturbed Parameterization Tendency (SPPT) for model error sampling, Local Ensemble Transform Kalman Filter (LETKF) for IC uncertainties, perturbation of LBCs testing different GCM or global ensemble combinations, and also new verification methods able to cope with spatial patterns, such as the Method for Object-Based Diagnostic Evaluation (MODE). Here it is presented a historical review of the system, as well as an outlook to the main research lines to build a feasible AEMET-gamma-SREPS.

80 - EnKF and 4DVar data assimilation of Aura-MLS chemical observations

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Quentin Errera, Simon Chabrillat, Richard Menard, and Yves Christophe

Chemical transport models (CTM) coupled with a data assimilation scheme has been shown to be useful to improve the analysis/simulation and forecast of chemical species concentrations, support satellite mission concepts, and have shown some skill in deriving information about the non-assimilated chemical species. For several years, the Belgian Assimilation System for Chemical ObsErvations (BASCOE) consisting in a 3-dimensional CTM and 4-dimensional variational (4DVar) data assimilation approach has been successfully employed to assimilate stratospheric chemistry species. 4DVar method demonstrates high accuracy however requires the development and maintenance of an adjoint model. Unlike 4DVar, the ensemble Kalman filter (EnKF) requires no tangent linear or adjoint model. Another advantage of it is that EnKF is quite easy to implement. In this work, we assess the performance of EnKF recently set up into the BASCOE system and compare it with our 4DVar technique using real observations, Aura-MLS data, and the same initial error statistics.

81 - Ensemble of Background Models Approach to Ionospheric Data Assimilation Initialization

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The Space and Geophysics Laboratory, of the Applied Research Laboratories at the University of Texas at Austin, has an established ionospheric research program with a mature 3DVAR data assimilation code (TRIPL-DA) for ionosphere specification. Ionosphere specifications are limited by uncertainties in the background, uncertainties in the data, and uncertainties contributed by the computational representation of the underlying algorithms. Mature techniques exist for understanding data uncertainties and computational algorithms. However, current ionospheric models necessary to populate the background are not well-characterized. The ensemble of models technique, now a standard tool in tropospheric weather forecasting, offers a method to better quantify the background uncertainties and possibly reduce them as well. Improved understanding of background uncertainties will improve the overall fidelity of the output of TRIPL-DA. Using an ensemble approach, we capitalize on the relative strengths of several standard climate-based ionospheric models (IRI, RIBG, etc.) as a function of the physical space. An improved background specification should reduce the overall computational cost of the 3DVAR method, while simultaneously showing improvement in the specification of variances (uncertainties). We describe the techniques used to create an ensemble out of several incomplete background models, and present a comparison of the ionospheric specification for the March 2012 Solar Event for the current simple background versus the background produced by the ensemble of models technique.

82 - Stochastic reconstruction of the flow in the Earth's outer core from 170 years of observatory data

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Dominique Jault, Christopher Finlay

We consider the problem of core dynamics reconstruction, for which we differentiate between stochastic and deterministic forces that sustain the flow evolution. The former is associated with the impossibility of completely representing the forces as the magnetic field is not resolved at small length-scales. An illustration of the latter is the propagation of torsional Afven waves at inter-annual periods. However, this only concerns a tiny part of the observed geomagnetic secular variation (GSV), for which a dynamical understanding still has to be developed.
This quest requires to build a consistent model for the GSV uncertainties, in order to best extract the information contained in magnetic records. If progresses have been made along those lines over the past decade, GSV error statistics still need to be improved. Here we propose a stochastic approach by which all the prior statistical information about the GSV is formally accounted for, through a dense covariance matrix for both measurement and modelling error.
We give an example in the simplest case where the prior on the flow trajectory is a random walk (zero deterministic component), by inverting for flow increments backward in time, starting from the best constrained satellite era. The consistency between the flow and GSV priors is discussed. We propose an extension of this work where both deterministic and stochastic forces are considered, within the framework of data assimilation.

83 - Use of Green's function in spatial covariance analysis

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For numerical weather prediction, covariance plays a very important rôle in both ensemble and variational data assimilation. This research discusses possible applications of Green's function to covariance analysis. Since Green's function is an integral kernel that it can be used to solve partial differential equations for analysing the spatial statistical behaviour of forecasting error. By analysing error spectral statistics of Green's function, the linkage between the Green's function and covariance can be established. For example, from the Helmholtz differential equation for forecast

error statistics, the covariance is the square of the Green's function after it performs the spectral transform. The possible use of Green's function for variational and ensemble data assimilation will also be discussed.

84 - Coupled Model Parameter Estimation: Opportunities and Challenges
Shaoqing Zhang: GFDL/NOAA, Princeton University, Princeton, USA

Traditional coupled data assimilation that uses observations from the climate observing system to only estimate climate states can produce artefacts in the estimated variability and cause prediction drift due to the existence of model biases. With ensemble methodology, a new strategy for climate estimation and prediction initialization uses climate observational information to optimize both coupled model states and parameters. The new climate estimation method can produce a much better fitting between the coupled reanalysis and observations. The new initialization strategy in which the prediction model not only starts from observation-optimized coupled states but also uses observation-optimized model parameters can significantly reduce model drift in predictions. This presentation summarizes the research advances in the ensemble coupled model parameter estimation and discusses the challenges of applications in CGCMs.

Session 11. ***Evaluation and Validation***

85 - On the evaluation of probabilistic forecasts of vector variables
Martin Leutbecher: ECMWF - United Kingdom

Until now, most studies assessing NWP ensembles have focused on the probabilistic skill of individual scalar variables. However, ensemble forecasts can be used to predict the joint probability distribution for vector variables. Examples of such vectors are (i) temperature, wind speed and precipitation, (ii) two wind components, (iii) one variable at several spatially or temporally separated points.
Multivariate verification of probabilistic forecasts is an important topic for all users with applications that depend on functions of more than one variable. Moreover, multivariate verification may help guiding developments of the representation of uncertainties in ensemble prediction systems and ensemble assimilation systems if the reliability of the predicted covariances is sensitive to the methodologies used for perturbing initial conditions and model tendencies.
The talk focuses on the reliability of the predicted covariances and proper scores for joint probability distributions such as the energy score and the logarithmic score. The first part of the talk describes results obtained from idealised examples with hypothetical flow-dependent variations of the covariance. The second part of the talk will summarise multivariate verification results obtained with the ECMWF ensemble prediction system.

86 - Multiscale Surface Field Verication for Ensemble Tropical Cyclone Forecasts
David Smith: Bureau of Meteorology - Australia. dhsmith@bom.gov.au
M. Naughton, A. Sulaiman

The Australian global and regional ensemble prediction system operates with 24 members to provide daily short and medium range weather forecasts up to 10 days lead time. Extreme weather events such as tropical cyclones are expected to play an important role in future operational use of the ensemble system, and associated forecast verification provides valuable performance assessments.
A standard ensemble verification device is the spread-skill curve, which plots domain averaged ensemble mean error together with associated spread about the ensemble mean, at a series of forecast lead times. For well calibrated ensembles the two curves are closely matched, however under-spreading is common, particularly in the later stages of a forecast. Domain averaged spread-skill curves, while valuable in their own right as a diagnostic tool, can hide local features and error structures of potential importance.

By utilising spherical wavelet transforms constructed on quasi-uniform geodesic grids as a spatial filter, this presentation will probe spread-skill curves on multiple scales, for selected ensemble forecasts of recent tropical cyclones in the Australian region. Considering mean sea level pressure and surface wind components, verified against analyses, dominant error scales and local features will be shown, providing some unique insights into the spatial error structure. In terms of under-spreading, the filtering process also reveals evidence of preferred scales, in each of the fields considered.

87 - Ensemble copula coupling: Application to the ECMWF ensemble
Roman Schefzik: University of Heidelberg, Institute of Applied Mathematics – Germany.
Thordis Thorarinsdottir, Tilmann Gneiting

Ensemble forecasts call for statistical post-processing, in that model biases and dispersion errors need to be addressed. Methods such as Bayesian model averaging (BMA) and ensemble model output statistics
(EMOS) achieve this for single weather variables at single locations and single look-ahead times, but fail to recognize spatial, temporal and inter-variable dependence structures.
Ensemble copula coupling (ECC) is a three-stage procedure that addresses this challenge, in that the (discrete) ensemble copula is applied to the individually post-processed predictive distributions, in ways described in a companion talk by Tilmann Gneiting. The key idea is that the ECC post-processed ensemble inherits the multivariate rank dependence structure from the raw ensemble, thereby capturing the flow dependence. The result is a post-processed ensemble forecast of spatio-temporal weather trajectories that is physically consistent and calibrated.
We compare various variants of ECC in an application to the 50-member European Centre for Medium-Range Weather Forecasts (ECMWF) ensemble over Germany, and demonstrate improved predictive performance relative to both the raw ensemble and state of the art methods of univariate post-processing.

88 - Proper divergence functions for comparing and combining climate model outputs for extreme temperature indices
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Nadine Gissibl and **Tilmann Gneiting**, Heidelberg University, Germany

Divergence functions provide a quantitative assessment of the difference between two probability distributions F and G. These functions are widely used for verification in prediction settings, where F is a predictive distribution function and G is the empirical distribution function of the events that materialize. If F is a prediction for a single event y, the quality of the prediction is instead assessed by a scoring rule. Scoring rules are said to be proper if the expected score is optimized when F is the true distribution of y. This property encourages honesty in the prediction process and prevents hedging. We propose a similar property for divergences where divergence functions associated with proper scoring rules are always proper. For prediction assessment, the use of the energy distance, the divergence function associated with the continuous ranked probability score, is recommended. In a case study, an ensemble of fifteen different climate model projections for monthly maximum and minimum temperatures over Europe from 1961 to 1990 is compared to two sets of re-analysis data for the same time period. Further, we discuss how this framework may be applied to obtain weights for an optimal combination of the different ensemble members.

89 - The implementation of BMA method at a limited area ensemble system
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Andras Horanyi - ECMWF
Mate Mile - Hungarian Meteorological Service
Sandor Baran - University of Debrecen

Ensemble Prediction Systems (EPS) contain various number of model forecasts which can estimate the probability distribution function of the future weather variables. The raw distribution functions are usually « sharp », uncalibrated and not always in accordance with the statistical distribution of the given variable.
In the present work Bayesian Model Averaging (BMA) is applied for calibrating ensemble wind speed and temperature forecasts. In the BMA method all EPS members belong to a distribution function which is variable specific and tuned statistically. The sum of these distributions can represent the final calibrated forecast which should be more accurate than the original one.
The ensemble calibration is realized for the Limited Area Model Ensemble Prediction System of the Hungarian Meteorological Service (ALADIN-HUNEPS). Different variants of the BMA method are investigated and the latest results are shown.

90 - Comparison of hybrid ensemble/4D-Var and 4D-Var within the NAVDAS-AR data assimilation framework

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Thomas E. Rosmond, Craig H. Bishop, Justin McLay, **Nancy L. Baker** (1)
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The effect on weather forecast performance of incorporating ensemble covariances into the initial covariance model of the 4D-Var Naval Research Laboratory Atmospheric Variational Data Assimilation System-Accelerated Representer (NAVDAS-AR) is investigated. This NAVDAS-AR-Hybrid scheme linearly combines the static NAVDAS-AR initial background error covariance with a covariance derived from an 80-member flow-dependent ensemble. The ensemble members are generated using the Ensemble Transform technique with a 3D-Var based estimate of analysis error variance. The ensemble-covariances are localized using an efficient algorithm enabled via a separable formulation of the localization matrix. We describe the development and testing of this scheme which allows for assimilation experiments using differing linear combinations of the static and flow-dependent background error covariances. The tests are performed for two months of summer and two months of winter using operational model-resolution and the operational observational data set -- which is dominated by satellite observations. Results show that the hybrid mode data assimilation scheme significantly reduces the forecast error across a wide range of variables and regions. The improvements were particularly pronounced for tropical winds with a greater than 5% reduction in vector wind RMS differences from verifying analyses out to 48 hrs lead time at all 8 vertical levels examined. The average improvement across geopotential height and vector winds at multiple levels and lead times was a reduction of 2.6% RMS errors.

91 - Using Shadowing Ratios to evaluate data assimilation techniques

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Leonard Smith

Identifying successful "noise reduction" as such remains a challenge in applications where the "true" values are not know a priori. We suggest shadowing ratios as a measure of noise reduction when the task at hand involves prediction. Initial condition uncertainty will more or less always limit the lead time of a chaotic model, even when that model reproduces the system dynamics perfectly. Since in reality, observations from such systems tend to be clouded by measurement error, the maximum lead time we can expect to accurately predict using the model will be short. Data assimilation techniques attempt to improve our state estimates, we introduce a new measure which allows us to estimate the quality of these techniques. A model trajectory shadows for as long as it is consistent with the noise model of the observed states. We deﬁne the shadowing ratio as the ratio of the length of time the model shadows using the assimilated initial conditions to

the length of time the model shadows using some reference data assimilation technique. We use the measure to evaluate the effectiveness of one assimilation technique in particular, Gradient Descent of Indeterminism (GDI). Using the Moore-Spiegel system as an example we ﬁrst use shadowing ratios to show the effect of using different numbers of observations from the past when applying GDI. We then compare GDI to other assimilation techniques using the measure to compare the effectiveness from a forecasting perspective. Finally, since GDI requires derivative information from the system, we compare the effectiveness of the algorithm when using the exact derivative matrix and when approximating using a forward difference technique. Other aspects of GDI are discussed, in the context of ﬁltering and noise reduction.

92 - A Comparison of Three Ensemble Data Assimilation Methods Considered as Ensemble Estimators

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Wael Silini, Mohamed Jardak & Olivier Talagrand

A comparison of three ensemble data assimilation methods is presented. The EnKF, ETKF and the Ens/4D-Var lters are implemented for different twin experiments varying from the Lorenz63 model to the shallow-water model on the sphere. The strengths and weaknesses, of each of the above methods, are illuminated by examining the assimilations analysis root-mean-squared error (RMSE) and by employing tools from ensemble forecast verification such as rank histograms, reliability diagrams and Brier scores.