Implementation and Research on the Operational Use of the Mesoscale Prediction Model COAMPS in Poland

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LONG-TERM GOALS

Our long-term goal is to implement an operational high-resolution atmospheric data assimilation and prediction system and to use it for daily weather forecasting. In this project, we have worked on several operational and scientific aspects of the problem using the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®[1]): (a) setting up stable large-scale data transfer capability to facilitate COAMPS runs 2-4 times per day in an operational manner for different geographical regions and using different nested grid configurations; (b) perform research on the MPI scalability of COAMPS on selected computer architectures and to optimize the code to take advantage of the vector capabilities of the Cray X1 and the massively parallel features of our Linux cluster; (c) identify and understand the uncertainties in high-resolution NWP forecast and their impact on severe weather, such as extreme rainfall, and to develop model metrics appropriate to mesoscale weather phenomena; and (d) improve our knowledge of observational error characteristics for spatially-correlated data and develop the numerical schemes capable of assimilating these types of observations.

OBJECTIVES

The objectives of this project are to: (a) implement an operational data feed from the Navy Operational Global Atmospheric Prediction System (NOGAPS), and implement a operational version of COAMPS

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[1]   COAMPS® is a registered trademark of the Naval Research Laboratory.

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14. ABSTRACT

Our long-term goal is to implement an operational high-resolution atmospheric data assimilation and prediction system and to use it for daily weather forecasting. In this project, we have worked on several operational and scientific aspects of the problem using the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS?1): (a) setting up stable large-scale data transfer capability to facilitate COAMPS runs 2-4 times per day in an operational manner for different geographical regions and using different nested grid configurations; (b) perform research on the MPI scalability of COAMPS on selected computer architectures and to optimize the code to take advantage of the vector capabilities of the Cray X1 and the massively parallel features of our Linux cluster; (c) identify and understand the uncertainties in high-resolution NWP forecast and their impact on severe weather, such as extreme rainfall, and to develop model metrics appropriate to mesoscale weather phenomena; and (d) improve our knowledge of observational error characteristics for spatially-correlated data and develop the numerical schemes capable of assimilating these types of observations.

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at the Interdisciplinary Centre for Mathematical and Computational Modelling (ICM), Warsaw University; (b) validate COAMPS model performance through inter-comparisons with statistics obtained from the United Kingdom Meteorological Office (UKMO) unified model; (c) investigate the scalability of COAMPS on ICM computers, a 200-processor OPTERON cluster and a Cray X1; and (d) develop a data assimilation scheme that can assimilate remotely-sensed and non-conventional data sources with a special emphasis on Doppler radar data. Meeting these objectives will allow the Polish National Air Defense to issue 1-5 day mesoscale weather forecasts in the regions of their interest, including Poland and Central Europe.

APPROACH

Our approach is to utilize NOGAPS for initial and lateral boundary conditions, and the nested COAMPS model for mesoscale atmospheric forecasts. The NOGAPS fields are obtained from the Global Ocean Data Assimilation Experiment (GODAE) server at the Fleet Numerical Meteorology and Oceanography Center (FNMOC) and transferred to ICM in automated (machine-controlled) efficient and stable way, thanks to support from FNMOC. We ported the COAMPS system to the ICM Linux cluster and Cray X1 computers and measured system performance and scalability using tools developed in-house for model verification. The unique aspect of our capabilities is that we concurrently run the UKMO mesoscale model on a grid that is similar to the one used by COAMPS. We will also investigate the time evolution of the conditional forecast (background) error probability density function using an ensemble of the model forecast to generate background error statistics. This helps us to identify and understand the uncertainties in high-resolution NWP forecasts on high-impact weather, particularly extreme rainfall. Finally, we will study observational error characteristics of radar reflectivity and radar radial winds. Such observations have the potential to provide detailed information to improve mesoscale analyses and forecasts. We will study historical weather events for which we have radar data to understand the observational error characteristics. We will investigate how they may be applied in data analyses used for assimilating radar data into numerical weather prediction models.

WORK COMPLETED

During FY08, we accomplished the following tasks: (a) made a revised set-up of the US Navy COAMPS system on ICM machines at Warsaw University for the purpose of providing operational support to the Polish Forces using the direct connection of ICM with the Military Meteorological Office, (b) improved some parts of the COAMPS system (e.g., more frequent boundary conditions, variable step in interpolated boundary data and tested version 4.2.2 of the COAMPS model, (c) installed the wave model WAM4 forced by surface winds forecasted by the COAMPS model, (d) investigated the sources of uncertainty in model forecasts and observational data, (e) worked on the development of the entity based approach to the verification of precipitation patterns predicted by the COAMPS system, and (f) worked on the development of the ensemble Kalman filter approach for the purpose of assimilating radar reflectivity and radial wind data in COAMPS.

RESULTS

During FY08, we further increased the frequency of lateral boundary conditions transmitted from the GODAE server to our model domains. Using the COAMPS restart capability, we implemented three restart runs with different frequencies for the interpolation of lateral boundary conditions (LBC). For the forecast period from 0 to 48h we used LBC data in 3h intervals, for the period from 48 to 84h we used LBC data in 6h intervals, and for the period from 84 to 120h we used LBC data in 12h intervals.

These changes in LBC frequency resulted in improved prediction of selected meteorological elements, such as more accurate prediction of the position and intensity of low and high pressure centers, and more accurate prediction of precipitation patterns. We also introduced some changes into the configuration of our model domains. Two independent domains of our forecast were designed. The first one, called NAE, covers the North Atlantic and European area, and consists of 3 nested grids with different spatial resolutions and forecast lead times. The coarse grid has 193x127 grid points with a mesh size of 39km and lead time of 120h; the second one, placed over Central Europe, has 169x217 grid points with a mesh size of 39 km and lead time of 84h; and the third one, placed over Poland, has 193x175 grid points with mesh size of 4.3 km and lead time of 48h. Our second domain, called ME, covers Middle Eastern countries, and consists of two nested grids. The coarse grid has 117x71 grid points and a mesh size of 45 km, and the inner grid has 259x127 grid points and a mesh size of 15 km. Both grids have lead times of 72h. This domain is used to support military activities of Poland in NATO and UN operations.

The official web page of the COAMPS model at ICM has been slightly rewritten and tailored to the needs of our general public users. Starting in mid-2008, the COAMPS web page is posted at: http://meteo.icm.edu.pl/. On this page, three different models (4m UM, 13 km COAMPS and 13 km WAM) used operationally at ICM are presented, so the user can compare the results of both atmospheric models and get information about the state of the sea by looking at the results of the wave model. As an example, Fig. 1 shows the 24h forecast of the significant wave height and the mean wind direction from the wave model.
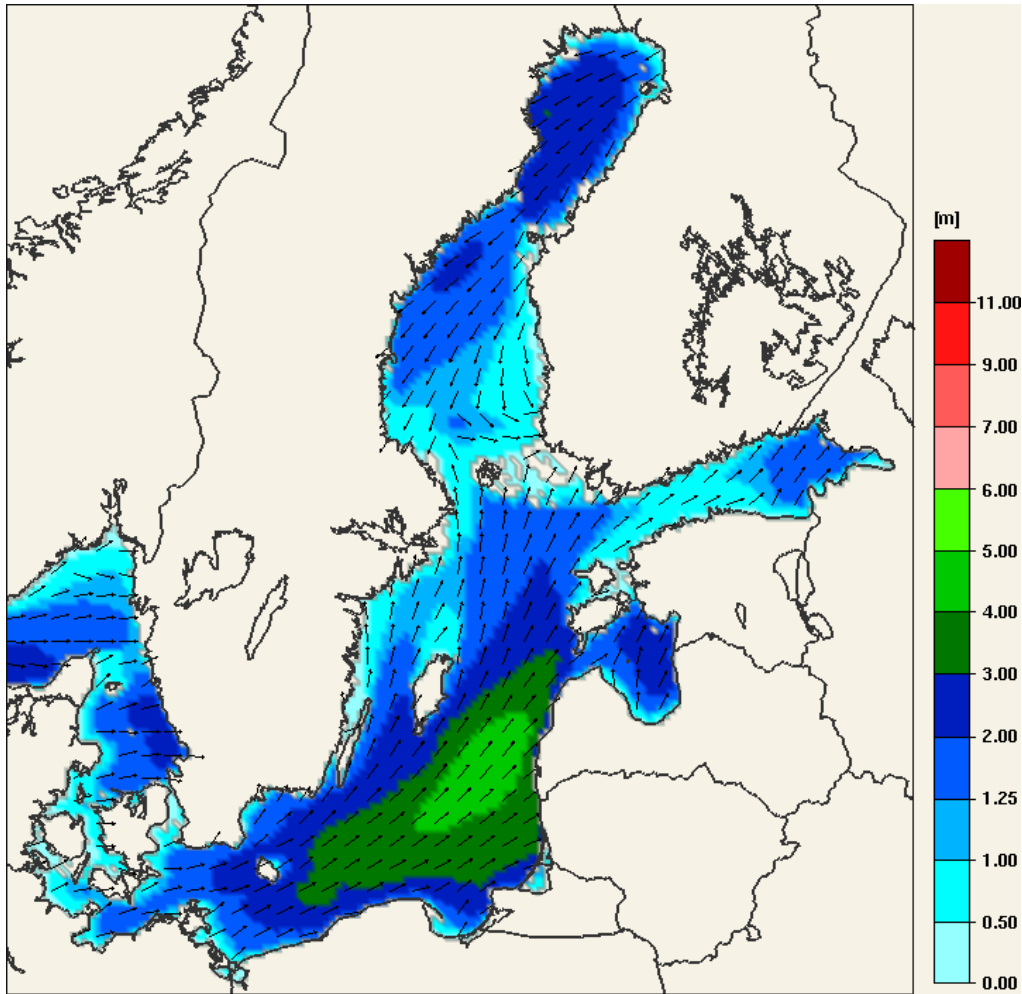
***Fig. 1. Example of the wave model WAM4 forecast of significant wave height and mean wave
direction valid at 3 Oct 2008, 00Z***

In addition to this official web page, we have also developed a second web page
(http://coamps.icm.edu.pl), where selected results, both at the near surface level and at a few levels in
free atmosphere are presented for all nested grids for both the NAE and ME domains.

The second field of activity within this project in FY08 was the development of a entity based scheme
of verification of precipitation patterns produced by the COAMPS system. Precipitation forecast
generated by the numerical weather prediction model give a quantitative picture of rainfall event
including rain area, rain intensity, and location of rain systems. Errors can occur in all of the above
quantities. In our approach to the verification of precipitation forecasts, the object-oriented method
using the definition of a contiguous rain area has been implemented. A contiguous rain area (CRA)
introduced by Ebert and McBridge (2000) is defined as a region bounded by a user-specified isohyet in
the forecast and the observations. Using a pattern matching technique, the method is able to determine
the location error, the intensity error and the pattern error. Observations and forecast fields are
assumed to be on the same spatial grid. We developed software which enables us to produce the
forecasts and radar observations on common projections and with the same resolutions. The fields are

merged together by overlying the forecast on the observations. An "entity finder" is applied to isolate distinct contiguous rain areas. The forecast is translated over observations until a best-fit criterion is satisfied. This method requires the forecast and observation entities to overlap at a little bit. To develop an algorithm of the pattern matching technique, we examined a number of candidates to meeting these criteria: closest entities pick their pairs first; large entities pick their pairs first; intensive entities pick their pairs first. We chose the pairing for which sum of all local errors is minimal.
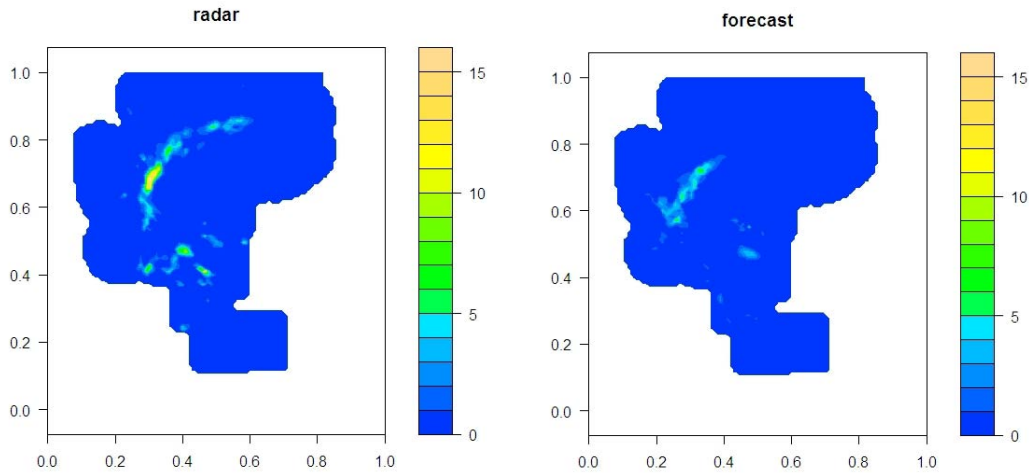

Fig. 2. Composite 3h precipitation pattern estimated form observed radar reflectivity (left panel) and 3h precipitation totals simulated by COAMPS model (right panel).

In our first series of experiments, we concentrated on the entity based precipitation verification using an ensemble of COAMPS model runs for moderate (20 km) resolution. The verification area presented on Fig. 2 is limited to the area covered by the radars (in our case, the Baltic Sea catchment). Based on the location of the precipitation and its intensity, the event contingency table can be constructed. We found that the most common type of the error was a missed location.

The third field of activity within this project in FY08 was the improvement of the knowledge of observational error characteristics for spatially correlated data. We used polar volume data from the Baltic weather radar network and corrected the observed reflectivities for topographical beam blockage by applying a Beam Propagation Model (BPM, Bech et al. 2007). The BPM simulates the radar's field of view considering the scan geometry, the topography, and the atmospheric conditions. Topography is described by a digital terrain model with 1 km horizontal resolution. To consider realistic atmospheric conditions we used profiles from the COAMPS model and radiosonde data as input for the BPM. To facilitate computations the correlation function for reflectivity errors is assumed to be separable. This gives us the chance to split the correlation function into a vertical and a horizontal component.
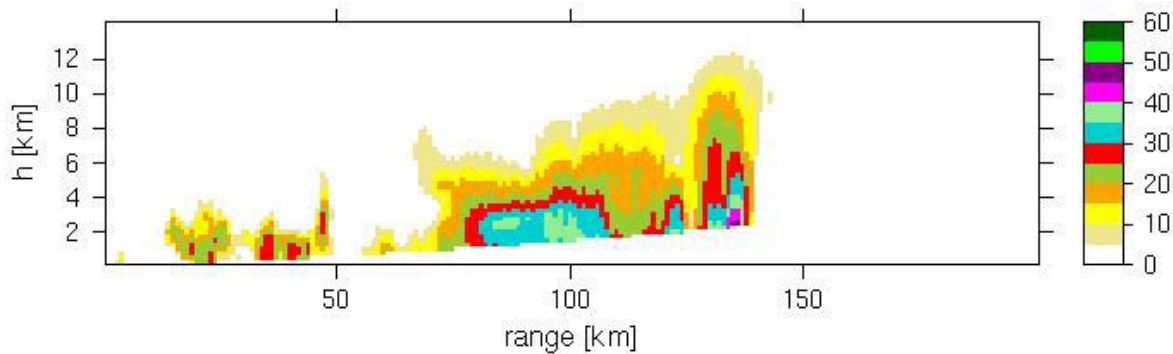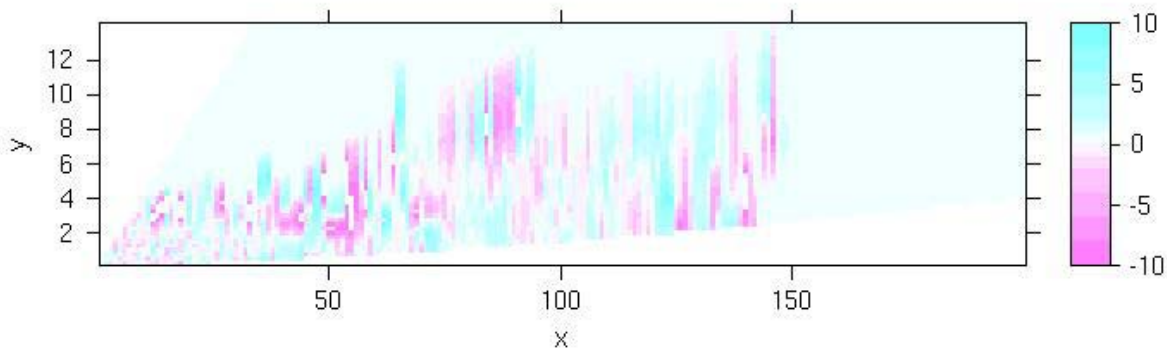
brz 200707041120 Reflectivity at azimuth angle 63
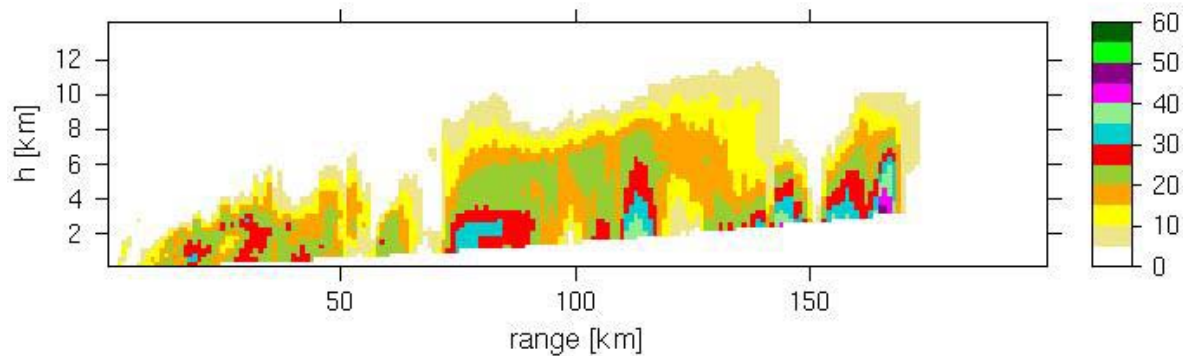
background error of reflectivity
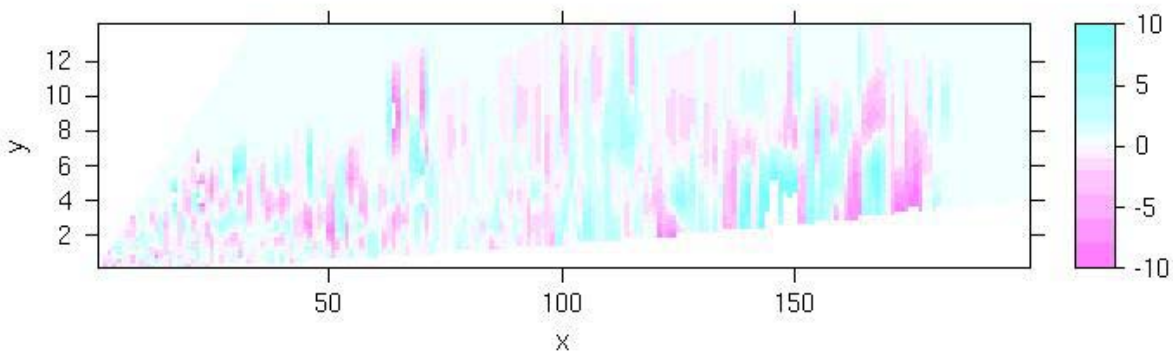
## brz 200707041120 Reflectivity at azimuth angle 110

background error of reflectivity

Fig. 3. Background error of reflectivity in azimuth-height plane

In Fig. 3, the background error of reflectivity for one of the Polish radars (i.e., Brzuchania), is presented. Only positive values of reflectivity are shown. After testing different correlation models we finally selected the Gneiting model (Gneiting and Schlather 2004) with four input parameters (variance, scale, mean, and nugget). Variance and scale are estimated from a reflectivity sample, while mean and nugget are assumed to be zero.


(a) uncorrected data (3D)   (b) corrected data (3D)
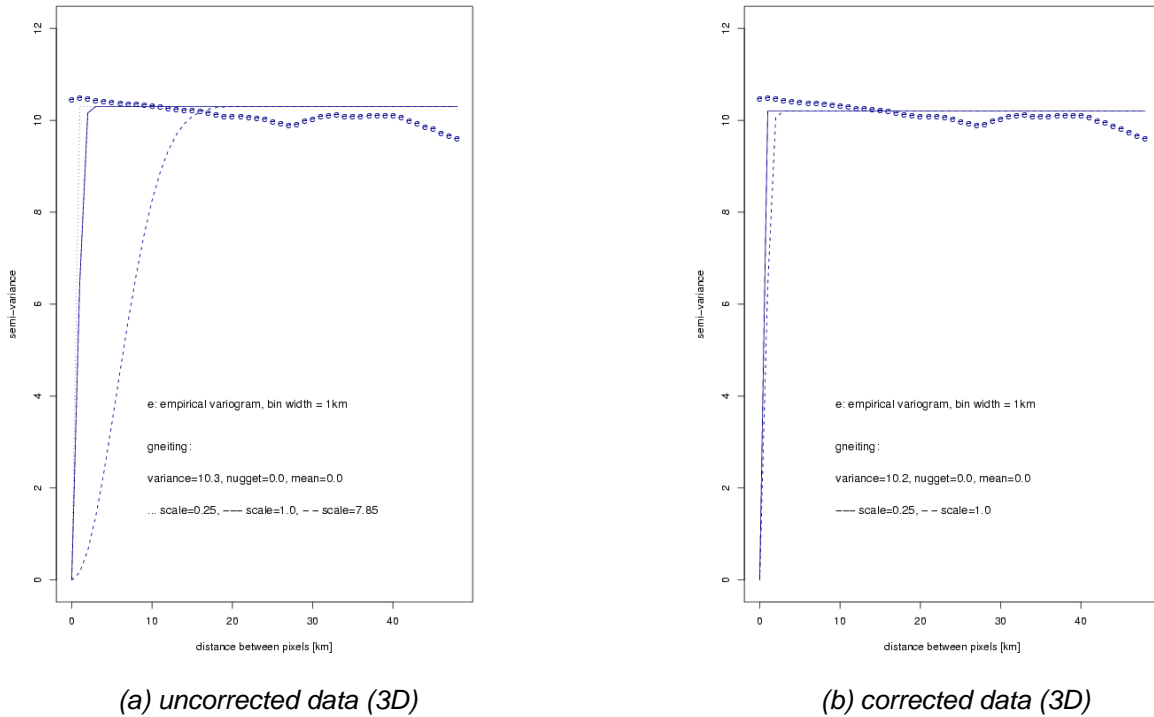
Fig 4: Empirical and parametric vertical variograms of reflectivity errors for the Östersund radar on 29 July 2007 1200 UTC. The BPM has been used to correct reflectivities for topographical beam blockages assuming standard propagation.

Results of this work show that BPM is able to correct topographical beam blockage under standard propagation conditions and to simulate anomaly propagation. The Gneiting model is a useful tool to estimate observation error correlations. Reflectivity errors are vertically uncorrelated at distances greater than a few kilometres. This is also valid for the horizontal plane. Beam blockage correction has a positive effect on the computation of observation error correlations.

Another field of activity within this project in FY08 was the work on an ensemble data assimilation system based on the Kalman square root filters. The filtering approach to data assimilation has been studied by others for about 20 years. The goal of the ensemble square root filter is to estimate the true system state and the uncertainty of estimate by evolving of model states in time. Our basic programming tools is the DART software package developed in NCAR. This tool can be implemented to the whole spectrum of the atmospheric models, from simple one-dimensional Lorenz model to the sophisticated numerical weather prediction model such as WRF or COAMPS. In the case of filtering methods applied to a complicated NWP model with a huge state vector, the need to accurately estimate

covariance structures from finite and small sample is a challenging task. In FY08, we focused on two implementations of DART: (1) investigation the role of the covariance inflation to the results of assimilation using the L96 Lorenz model, and (2) more advanced experiments with the isentropic primitive equation two-layer model. An additional processing of the ensemble covariances is introduced to avoid the filter divergence caused by sampling errors.
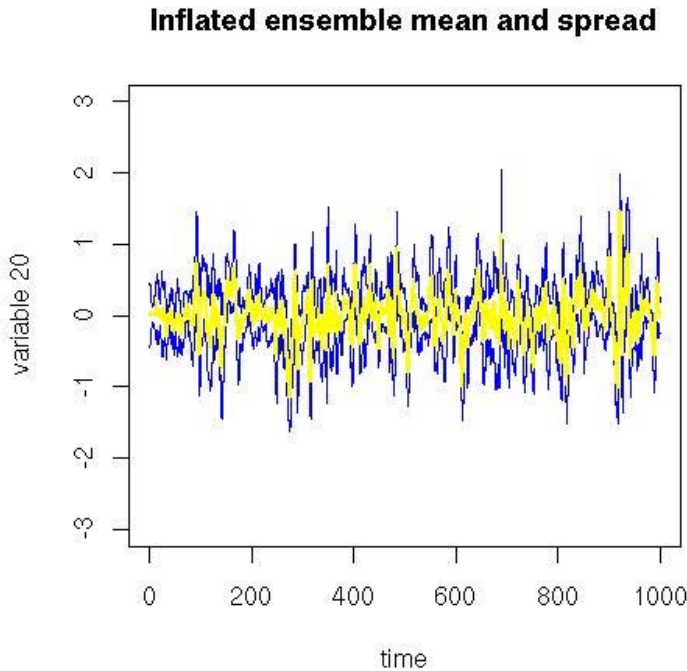

Fig. 5 Inflated ensemble mean and spread of 20 variable of the Lorenz L96 model

The techniques commonly used are distance dependent covariance localization and covariance inflation. Covariance localization is a filter that forces the ensemble covariances to go to zero at some distance from the observation being assimilated. Covariance inflation inflates the deviations from the ensemble mean first guess by some factor greater than 1.0 for each member of the ensemble, before the computation of the background-error covariances and before any observations are assimilated.

The isentropic primitive equation two-layer model on a sphere described by Zou at all has been implemented into DART by Jeffrey Whitaker. The fluid system governed by this model consists of two layers of constant potential temperature on a rotating sphere. In such a model, the horizontal momentum equations require that u an v must remain independent of height with each layer if they are initially independent. The dynamics of each layer is then similar to that of shallow-water model.
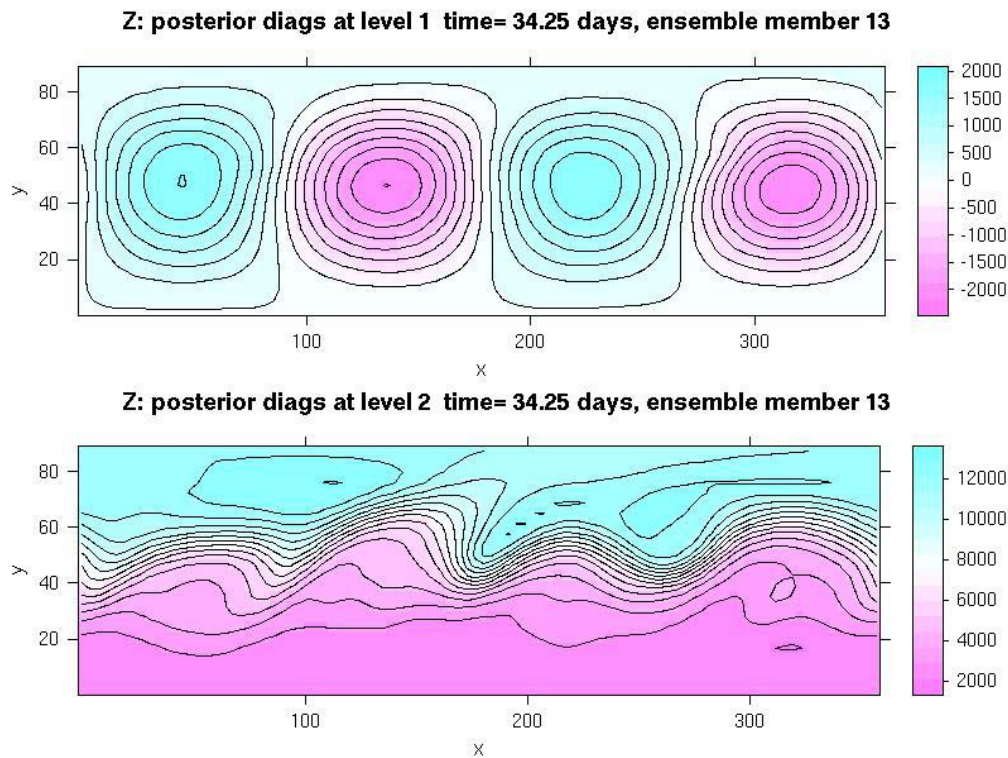
Fig. 6 Results of integration of pe2lyr model for ensemble 13 after 34.25 days

The isentropic model is much more realistic than the Lorenz L96 model. We did some experiments with the covariance inflation implemented in the isentropic model. The results of our experience in the specification of the localization function and the covariance inflation with these two models are positive. In future work in this area, we plan to focus on data assimilation experiments with the COAMPS model, as we know from personal information from Jeffrey Anderson that the work on the implementation of the COAMPS model into the DART environment is very near completion.

PERSONNEL EXCHANGES AND TRAVEL COMPLEMENTED

Oskar Kapala, University of Warsaw – participated in EGU General Assembly, Vienna Austria 13-18 April 2008, giving a poster presentation.

Bogumil Jakubiak, University of Warsaw – participated in EGU General Assembly, Vienna Austria 13-18 April 2008, giving two posters presentation.

Mikolaj Sierzega, University of Warwick – participated in Joint MAP D-PHASE Scientific Meeting – COST 731 mid-term seminar, 19-22 May 2008, Bologna, Italy, giving oral presentation.

Bogumil Jakubiak, University of Warsaw – participated in Joint MAP D-PHASE Scientific Meeting – COST 731 mid-term seminar, 19-22 May 2008, Bologna, Italy, giving one oral and one poster presentation.

Bogumil Jakubiak, University of Warsaw – participated in ERAD Fifth European Conference on Radar in Meteorology and Hydrology, 30 June – 4 July 2008 Helsinki, Finland giving one poster presentation.

IMPACT/APPLICATIONS

The operational version of the high resolution mesoscale model was implemented. This will improve 5-day forecasting for aviation and for support of Polish troops in Afghanistan and Iraq.

TRANSITIONS

None.

RELATED PROJECTS

US GODAE project – The Global Ocean Data Assimilation Experiment (GODAE) provides regular, complete descriptions of the state of the ocean and the atmosphere in support of operational oceanography and oceanographic research. We use the GODAE server data for our COAMPS predictions. The GODAE Monterey server is maintained by FNMOC and is sponsored by the Office of Naval Research (ONR).

COST Action 731 project – Propagation of uncertainty in advanced meteo-hydrological forecast systems. Within this action, we started to develop a radar data assimilation scheme using the ensemble Kalman filter approach.

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