Abstracts Talks

Mon. 09:10 - 10:00 | Alan Geer

Assimilation of microwave observations in allsky conditions at ECMWF

Microwave observations are assimilated operationally at ECMWF in all sky conditions, whether clear, cloudy or precipitating. Assimilation of mager channels (sensitive to cloud, precipitation and lower tropospheric moisture) and water vapour sounding channels (sensitive to mid and upper-tropospheric moisture, cloud and precipitation) improves forecasts in the short and medium-range. As would be expected, humidity fields are improved, but dynamical forecasts are too, which is likely explained by the ability of 4D-variational assimilation to infer dynamical initial conditions from water vapour and cloud features. However, all-sky assimilation is still a work in progress. A fundamental issue is that cloud and precipitation features are not always co-located in the model and in the observations. If not properly understood, this issue can cause problems with spurious biases, double-penalty issues in statistical verification and violations of the tangent-linear hypothesis. Further, because data assimilation directly confronts the modelled cloud and precipitation with its observational equivalent, model problems can be very clearly exposed. For example, the ECMWF model appears to have difficulty creating supercooled liquid water clouds in `cold-sector' intrusions of polar air over the oceans; there are also issues with the diurnal cycle in stratocumulus regions. There are plenty of issues in radiative transfer modelling too, particularly in the treatment of cloud overlap and scattering from frozen particles. However, as this work continues, it will help improve cloud and precipitation forecasts both directly through better initial conditions and indirectly by driving improvements in the modelling of moist physical processes in the forecast model and radiative transfer in the microwave observation operator.

Mon. 10:30 - 11:20 | Ed Pavelin

Assimilation of cloudy infrared satellite observations: The Met Office perspective

Infrared radiances, particularly from hyperspectral instruments such as IASI, AIRS and CrIS, are one of the most important data types assimilated into NWP models. They contain useful information on temperature, water vapour concentration, cloud properties and surface variables. In the early years of direct radiance assimilation, the use of IR radiances was limited to clear-sky scenes, due to limitations in forward modelling and data assimilation techniques in cloudy situations. During the last decade, progress has been made in extending the use of IR observations to cloudy areas in order extract more temperature and humidity information. However, the assimilation of cloud information from IR radiances has proved to be more challenging, and work towards exploiting this information in operational NWP systems is still at an early stage.

In this talk I will first summarise the main strategies that have been adopted for dealing with cloud-affected infrared radiances at NWP centres. I will describe in more detail the scheme currently used operationally at the Met Office, describing its relative strengths and weaknesses. This will lead to a discussion of the ways in which the assimilation of cloud-affected radiances can be further developed, with the eventual aim of assimilating cloud information directly.

Mon. 11:20 - 12:00 | Alan Geer

Assimilation of infrared observations in all-sky conditions at ECMWF

At ECMWF, the use of cloud-affected infrared observations is less advanced than in the microwave. Mainly this is because the problem is harder in the infrared than in the microwave. Cloud fraction, cloud overlap and cloud top conditions are more important in controlling observed brightness temperatures, making it harder to accurately compute the observation equivalents and to infer useful information in data assimilation. The initial approach has been to assimilate observations only in fully overcast conditions. However, upper-tropospheric water vapour channels share many characteristics with their microwave equivalents and they are a promising area for the application of the `all-sky' techniques currently used in microwave assimilation. Work is ongoing to improve cloudy radiative transfer modelling, especially to make it computationally faster and not too memory-intensive, prerequisites for operational assimilation.

Mon. 14:00 - 14:40 | Marta Janiskova

Use of spaceborne cloud radar and lidar observations for experimental assimilation

Spaceborne active instruments, providing a three-dimensional characterization of clouds, promise a new dimensions of information to be used in numerical weather prediction (NWP) systems. Observations from CloudSat and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) are already available and new missions, such as EarthCARE (Earth Clouds, Aerosol and Radiation Explorer) should appear in the near future. The challenge is to assimilate such new data sources into NWP system to achieve a better knowledge about the atmospheric state, and possibly to improve the weather forecasts.

Research activities are ongoing at the European Centre for Medium-Range Weather Forecasts (ECMWF) to exploit these data for monitoring and assimilation.

In the presentation, the methodology explored for assimilation studies will be described. Information about the observation operators (moist parametrization schemes, reflectivity model and parametrization of lidar backscatter due to clouds), observation error definition and handling of observations (such as quality control and bias correction) will also be provided. Finally, the results from assimilation experiments using a variational technique to assimilate cloud observations from CloudSat and CALIPSO (separately or in combination) will be presented.

Mon. 14:40 - 15:20 | Pauline Martinet

Use of Microphysical Variables for the Assimilation of IASI Cloudy Radiances in Convective Scale Models

This presentation focuses on new developments for the assimilation of cloud-affected radiances from the Infrared Sounding Interferometer (IASI) into the convective scale model AROME with a focus on heavy rainfall events over the Mediterranean region. The radiative transfer model currently used (RTTOV) to simulate cloudy radiances assumes single layers of opaque cloud and requires the estimation of cloud parameters (cloud top pressure and effective cloud fraction). Due to the restriction of this cloud modelling to opaque scenes, very few infrared cloudy data are assimilated in an operational context. In this study, we propose to use the advanced radiative transfer model RTTOV-CLD that directly includes profiles of microphysical variables (liquid water content, ice water content and cloud fraction). This radiative transfer model enables a more realistic cloud representation taking into account multi-layer clouds and cloud scattering.
Firstly, the bias and the standard deviation of the innovations observation minus simulation are presented. A screening procedure to select homogeneous field of view in both observation and model spaces and to reject worthless cloud-affected radiances is also presented. This screening procedure based on the AVHRR imager is essential to have acceptable innovations but also Gaussian distributions of background and observation errors.
Secondly, this work presents one dimensional variational assimilation (1D-Var) retrievals. To that end, the cloud variables (liquid water content, ice water content) are added to the state vector and analyzed simultaneously with temperature and humidity. A new selection of 134 IASI channels were selected to improve the retrievals of cloud variables. With this new subset of channels, retrievals of temperature, humidity, liquid and ice water contents have been evaluated in the context of observing system simulation experiments and have shown encouraging results.
Finally, to prepare for the assimilation of cloudy radiances in the 3D-Var assimilation system of AROME, we evaluate the degree to which short-term forecasts can be improved if clouds are fully included in the assimilation system. To that end, a one-dimensional version of the AROME model is used to evaluate if the 1D-Var cloud increment can last during a 3 hour forecast. The evolution of the total cloud water content is compared when the AROME forecast is initialized with the analysis resulting from the 1D-Var or with the initial background. The gain of information brought by the analysis of the cloud variables in addition to temperature and humidity is also studied.

Mon. 15:20 - 15:40 | Gareth Dow

Cloud Assimilation at the UK Met Office - sensitivity studies in stratocumulus periods

Stratocumulus (Sc) is usually associated with quiescent weather patterns, in which there is a reduced tendency for data assimilation (DA) signals to be 'washed out' of the limited-area model domain by the lateral boundary conditions. The influence of errors in cloud analyses can persist longer than under more mobile regimes, affecting other variables such as screen temperature and visibility.

We demonstrate the contrasting impact of two sources of cloud data ('MOPS' and 'GeoCloud') for variational assimilation in the high-resolution Met Office UK models during two challenging Sc episodes. Our older MOPS scheme is a 3-d cloud fraction analysis synthesised from satellite cloud top data and surface reports. This has recently been succeeded operationally by the GeoCloud scheme, in which the same satellite cloud top data input to MOPS are instead assimilated directly as a set of cloud fraction columns.

Forecasts of the first Sc event using operational MOPS cloud data showed insufficient cloud breaks in the Sc sheet compared to observations, resulting in large screen temperature errors through to the end of the 36-hour forecast. Rerunning with GeoCloud data rather than MOPS gave a more accurate depiction of the cloud breaks over the UK and significantly better screen temperature forecasts.

The opposite scenario was encountered during a later Sc event, by which time GeoCloud data had replaced MOPS operationally. Forecasts during this period had a larger cloud deficit relative to the earlier episode. Rerunning with MOPS data in this situation managed to reinstate some of the missing cloud.

Mon. 16:10 - 16:50 | Jason Otkin

Exploring the impact of cloud-affected satellite observations in an ensemble Kalman filter assimilation system

Regional-scale Observing System Simulation Experiments (OSSEs) were used to explore how the assimilation of clear and cloudy sky infrared brightness temperatures within an ensemble Kalman filter assimilation system impacts the analysis and forecast accuracy at mesoscale resolutions (12-18 km). These studies assimilated observations that were sensitive either to cloud top properties and the 3D distribution of the cloud field or to water vapor in the lower, middle, and upper troposphere. Additional studies explored the impact of simultaneously assimilating cloud-affected observations from both satellite and radar observing systems.

Overall, the results revealed that the assimilation of cloud-affected infrared brightness temperatures had a large positive impact on the simulated cloud field, with the largest improvements occurring in the middle and upper troposphere. Wind and temperature analyses were most accurate when observations sensitive to clouds and water vapor in the upper troposphere were assimilated; however, the largest improvements in the cloud and moisture fields occurred after assimilating brightness temperature observations sensitive to water vapor in the lower troposphere. Even larger improvements were realized when both satellite and radar observations were assimilated since these observation types are sensitive to different portions of the cloud field. Sensitivity tests varying the covariance localization radius revealed that it was generally better to use a shorter radius when assimilating cloud-affected observations. Short-range precipitation forecasts were improved when cloudy observations were assimilated; however, the positive impact disappeared after several hours. These results demonstrate that the ability of cloud-affected satellite observations to improve not only the cloud and water vapor fields, but also the temperature and wind fields, enhances their utility within data assimilation systems.

Mon. 16:50 - 17:10 | Leonhard Scheck

Assimilation of MSG visible and nearinfrared reflectivity in KENDA/ COSMO

Satellite cloud observations are considered as important input parameters for convective scale data assimilation, as they contain a wealth of information about convective activity. However, current operational data assimilation systems in general utilize only clear sky thermal infrared and microwave radiance observations, which mainly provide temperature and humidity information. Due to the lack of suitable forward operators, visible and near infrared radiances, which contain information about cloud properties, are not considered.

To address this shortcoming, a fast forward operator for visible and near-infrared reflectance observations from MSG-SEVIRI is currently in development. A preliminary version of the operator has been completed and implemented in the expertimental km-scale Ensemble Data Assimilation (KENDA) system of DWD. The operator simulates synthetic satellite images from COSMO-DE model output and relies on the discrete ordinate method to solve the radiative transfer equation. The accuracy of the operator is typically better than 6%, compared to full 3D Monte Carlo results. A new version of the operator using a lookup-table based method allows for a reduction of the computational costs to a level that meets requirements for operational use and leads to only slightly increased errors.

First results from the assimilation of visible satellite observations are presented. The cloud water content in the analysis is successfully modified by the assimilation of SEVIRI images. The fast forward operator can also be used to investigate systematic differences between observed and synthesized satellite images. Preliminary results from such an investigation are discussed, which could prove useful in the identification of model deficiencies.

Mon. 17:10 - 17:30 | Annika Schomburg

Assimilating cloud information from satellite cloud products with an Ensemble Kalman Filter at the convective scale

An approach will be presented to extract cloud information from satellite cloud products based on SEVIRI data onboard the geostationary satellite Meteosat and assimilate this cloud information in the numerical weather prediction model COSMO at the convective scale with an ensemble Kalman filter.
Depending on whether an observed pixel is cloudy or cloud-free, different pseudo-observations are derived from the satellite cloud top height product, and the corresponding model equivalents are computed. These are cloud top height and relative humidity at cloud top height for cloudy scenes, and cloud cover at several levels for cloud-free scenes.

As a first test case a stable winter-time high-pressure weather situation has been chosen, to evaluate whether by assimilating the cloud information the simulation of the typical low stratus clouds can be improved. It is shown in single observation experiments, in data-dense hourly cycling experiments, and in a free forecast initialized based on the analysis including cloud data, that an improvement for the cloud cover in this weather situation is obtained. Clouds that are not properly represented in the first guess are enhanced in the analysis, and spurious cloud cover in the first guess, which has not been observed, can be reduced. Moreover through background error cross correlations reasonable effects on the temperature profiles are obtained. Comparing experiments with cloud data assimilation with experiments with only conventional data assimilation, the experiments with cloud information show more realistic cloud fields even after several hours forecast time.

Tue. 09:00 - 09:55 | Chris Snyder

Data Assimilation for Flows which Possess Many Scales of Motion

Tue. 10:25 - 11:20 | Thibaut Montmerle

Representing forecast errors at convective scale

In data assimilation, the weight of the prior state vector, or background, is given from its error covariance matrix. Due to the huge size of such vector in operational NWP systems, this background error covariance matrix (hereafter called B) cannot be easily estimated and not even stored.
Using a large Ensemble Data Assimilation (EDA) at convective scale coupled with a large EDA at global scale, based respectively on the AROME and on the ARPEGE NWP systems, flow dependency of background error parameters will be illustrated. At convective scale, much stronger anisotropies of local correlations and stronger gradients of variances will be in particular displayed compared to global scale.
Then, a non-exhaustive review of different methods that can be found in the literature to represent B will be presented. The two main frequent options, as well as their pros and cons, will be discussed: i) the modelization of B1/2 using a succession of invertible operators, generally calibrated using ensemble of forecast differences, and ii) the use of ensemble of perturbed forecasts whose sample dispersion matches the forecast error covariances. It will be finally shown that the merging of the two approaches into a hybrid B seems particularly promising, provided an efficient removal of sampling noise due to the limited ensemble size.

Tue. 11:20 - 12:15 | Milija Zupanski

Nonlinear ensemble data assimilation and all-sky MW and IR satellite radiance assimilation

Weather and climate data assimilation at high spatiotemporal resolution generally implies a need to include explicit cloud microphysical processes, which are highly nonlinear and associated with time-dependent uncertainty. Since clouds and precipitation are mostly observed using satellites, it is of interest to include assimilation of all-sky (cloudy and clear-sky) radiances in such a data assimilation system.

Therefore, we discuss the ever-increasing relevance of nonlinear data assimilation in high spatiotemporal resolution applications, such as severe weather and tropical cyclones. We also define and address the issues associated with assimilating all-sky microwave (MW) and infrared (IR) satellite radiances.

In this work we use various versions of the Weather Research and Forecasting (WRF) regional modeling system, as well as NASA and NOAA radiative transfer models. Examples of assimilated all-sky radiances include MW (AMSU-A, MHS, AMSR-E) and IR (MSG Seviri).

Tue. 14:00 - 14:55 | Dale Barker

Convective-Scale Data Assimilation Applications

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

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

The advent of operational probabilistic NWP, e.g. the 2012 implementation of the 2.2km/12km MOGREPS-UK system, introduces a fantastic new source of flow-dependent forecast uncertainty information for use in data assimilation. In parallel, convective-scale 4DVAR has developed to a level of sophistication where it is being actively considered for operational use in 2014-2015 by a number of centres. This talk will finish with comments on how the twin approaches of variational and ensemble data assimilation might be optimally leveraged in the next 2-5 years.

Tue. 14:55 - 15:50 | Siebren de Haan

The use of Mode-S Enhanced Surveillance Observations in NWP

Upper air atmospheric wind and temperature information is crucial for numerical weather prediction and nowcasting. The current observation systems which are exploited to collect this information are radiosonde, aircraft, wind profilers, Doppler radar and satellites. A novel method to measure wind and temperature is related to tracking and ranging by an enhanced surveillance (EHS) Air Traffic Control (ATC) radar. This EHS radar interrogates in a selective mode (Mode-S) all aircraft in sight on which the aircraft replies with a message containing for example magnetic heading, airspeed and Mach number. From this information wind and temperature can be inferred. Since meteorological information is not directly measured in this way, preprocessing is necessary to obtain atmospheric information with adequate quality. Using external sources of wind information, a heading and airspeed correction can be estimated for all aircraft when enough comparison can be generated. A dynamic heading correction database is created using the operational numerical weather prediction model from the European Center for Middle range Weather Forecast (ECMWF) and is cross validated with heading corrections derived using AMDAR wind information. Above 800 hPa, Mode-S EHS derived and AMDAR wind observations are comparable. Airspeed and heading corrected Mode-S EHS derived wind observations show to have a constant standard deviation (2 m/s) compared to ECMWF.

When locally received Mode-S EHS derived information is assimilated into a numerical model with a hourly update cycle, the three dimensional wind field is better for now-casting purposes than the operational forecast. The latter is available with an update frequency of once every three hours. The positive impact on wind in the first hours of the forecast gradually turns into a neutral impact, when compared to other wind and temperature observations. The gain for now-casting comes from the short latency of the forecasts combined with the high resolution of the observations.

Next, the impact of assimilation of Mode-S EHS derived information from a larger area exploiting the Dutch, German and Belgium Mode-S EHS radar information is presented. A very straightforward thinning scheme is applied. When assimilated in the hourly update cycle of HIRLAM7.4, an improvement in wind forecast is observed up to a forecast time of 9 hours for wind speed and wind direction. Especially, below 700 hPa a large improvement is observed up to 18 to 24 hours in range for wind direction forecasts.

Tue. 16:20 - 16:45 | Fuqing Zhang

Ensemble-based Assimilation of highresolution Doppler radar and in-situ observations for convective storms and tropical cyclones

Despite the inherent limit of messocale predictability, there are still significant rooms for improving the practical predictability of severe weather and tropical cyclones through advanced data assimilation techniques, better use of exiting or future observations and improved forecast models. Inter-comparison and coupling of various variational and ensemble based techniques for both severe weather and tropical cyclones will also be presented. Also presented will be a few techniques that include Super-observations (SOs), Successive Covariance Localization (SCL), Covariance Inflation through Relaxation to Prior approaches which we developed could be easily adapted to treat other dense and/or inhomogeneous observations that contains multi-scale information.

Tue. 16:45 - 17:10 | Atoossa Bakhshaii

WRF dual polarized radar forward operator

To equip the WRFDA with dual polarized radar data, the existing dual polarized radar forward operator in the ARPS model is adopted as part of the WRF microphysics package. The performance of the operator is studied by means of forecasting polarimetric signature of a supercell event in Central Germany. The comparison of single-moment and double-moment Morrison microphysics demonstrates that single-moment scheme does not capture all polarimetric signatures. However, the combination of two-moment microphysics and the dual-pol radar forward operator results a significantly more accurate demonstration of the supercell including low, and mid-level polarimetric signatures.

Future applications will include the assimilation of polarized radar data on the convection permitting scale to obtain quantitative precipitation estimates (QPE). This will be done either by a 3DVAR/4DVAR RUC configuration or a multi-physics ensemble forecasting system and is subject for future research.

Tue. 17:10 - 17:35 | Thibaut Montmerle

The AROME-France system : an operational NWP system at convective scale

Since 5 years now, Météo-France is running an operational NWP system at 2.5 km horizontal resolution over France, which aims in forecasting surface processes and local meteorological events such as convective systems or fog. This system, called AROME, is based on a 3h cycle of assimilation/forecast steps and makes use of an incremental 3DVar data assimilation.
Despite frequent displacement errors, AROME allows to represent realistically cloud and precipitations thanks to their explicit treatment of convection and their microphysical parameterization. In recent years, observation operators have been developed in order to assimilate observations that are sampled within such cloudy and precipitating areas (e.g by weather radars or by microwave radiometers), or that allow to characterize cloud top properties (e.g brightness temperature from infrared radiometers). When rain occurs, Doppler winds and reflectivities from radars allow nowadays to strongly reducing forecast errors of wind and of specific humidity.
To improve this system, different work directions are currently explored: 1h cycle at 1.3 km, assimilation of new observations such as radar data from the OPERA network, better representation of observation errors allowing the increase of the spatial density and a more optimal use of assimilated data.

Wed. 09:00 - 09:55 | Takemasa Miyoshi

Exploring Multi-scale and Model-error Treatments in Ensemble Data Assimilation

Ensemble data assimilation methods have been improved consistently and have become a viable choice in operational numerical weather prediction. Dealing with multi-scale error covariance and model errors is among the unresolved issues that would play essential roles in analysis performance. With higher resolution models, generally narrower localization is required to reduce sampling errors in ensemble-based covariance between distant locations. However, such narrow localization limits the use of observations that would have larger-scale information. This study aims to separate scales of the analysis increments, independently of observing systems. Inspired by M. Buehner, we applied two different localization scales to find analysis increments at the two separate scales, and obtained improvements in simulation experiments using an intermediate AGCM known as the SPEEDY model. Another important issue is about the model errors. Among many other efforts since Dee and da Silva?s model bias estimation, we explore a discrete Bayesian approach to adaptively choosing model physics schemes that produce better fit to observations. This presentation summarizes our recent progress at RIKEN on these theoretical and practical topics, and also introduces our future perspectives and challenges including ?Big Data Assimilation? for extremely-short-range weather forecasting using next-generation high-resolution weather simulations and supercomputers, and new observing instruments.

Wed. 09:55 - 10:15 | Andreas Rhodin

VarEnKF localisation for an unstructured grid

A new global forecast model (ICON) is under development at DWD. ICON is formulated on an icosahedral grid with local refinements and will replace both the current global (GME) and local (COSMO-EU, 7km) model.

The current global 3D-Var data assimilation system is further developed towards a VarEnKF. For a variable-resolution model as ICON, multi-scale localisation and analysis is an issue.

Localisation usually is achieved by application of a localisation matrix (Schur product) do the ensemble background error covariance matrix in spatial representation. Multi-scale localisation may be achieved by application of a localisation matrix in transformed representation. Candidates for scale-separating transformations on an irregular grid are wavelet transform formulations based on the lifting scheme.

The VarEnKF scheme under implementation at DWD will be described. Multi-scale localisation issues will be discussed and reasonings for specific choices of wavelet transformations are given.

Wed. 10:45 - 11:40 | Marc Buehner

Implementation of Four-Dimensional Ensemble-Variational Data Assimilation for Deterministic Weather Prediction

The final testing has been completed for a version of the ensemble-variational data assimilation approach (EnVar) to replace 4D-Var at Environment Canada for both global and regional deterministic weather prediction. This implementation of EnVar relies on 4D ensemble covariances, obtained from an ensemble Kalman filter, that are combined in a vertically dependent weighted average with simple static covariances. Verification results are presented from a set of data assimilation experiments to demonstrate the impact of several new components of the system, including: EnVar vs 4D-Var, a new observation bias correction scheme, an improved treatment of radiosonde and aircraft observations, assimilation of ground-based GPS observations and additional infrared observations, and an increased horizontal resolution.

Wed. 11:40 - 12:05 | Neill Bowler

Initial Trials of 4D-Ensemble-Var for Data Assimilation and Ensemble Initialization

Hybrid data assimilation schemes augment flow-dependent ensemble covariances with extra samples from a climatological covariance. Variational hybrids combine ensemble information with the existing investment in methods such as 4-dimensional variational assimilation (4DVar). However, the perturbation-forecast and adjoint models which 4DVar uses to evolve covariances over time impose significant computational and maintenance cost, and may not scale well on future massively parallel computer systems. 4D-Ensemble-Var (4DEnVar) offers an alternative approach, in which the temporal correlations are taken from the ensemble.

Results from early trials of 4DEnVar in the Met Office global NWP system show that for initializing a deterministic forecast 4DEnVar is superior to 3DVar and hybrid-3DVar, has similar average performance to 4DVar, but is inferior to hybrid-4DVar. 4DEnVar performs relatively worse in the Southern Hemisphere. However, the 4DEnVar system is a factor 3-6 cheaper than hybrid-4DVar, even though the latter has been optimized much more than the former. These cost savings could be recycled into extra resolution, extra ensemble members, and/or use of an outer loop.

The reduced cost of 4DEnVar makes it an attractive method for ensemble initialization. It has theoretical advantages over the ETKF currently used by the Met Office, in areas such as localization, re-linearization, the use of balanced variables, greater consistency with the way the central analysis is produced, and reduced maintenance costs. We will present the results of initial trials comparing 4DEnVar with the current ETKF in the global ensemble, including consideration of alternative inflation methods such as relaxation-to-prior-spread and additive inflation.

Wed. 12:05 - 12:30 | Jelena Bojarova

A 4-dimensional ensemble variational data assimilation for a limited area model

A 4-dimensional ensemble variational (4D-En-Var) data assimilation has been developed for a limited area model. The integration of TL and AD models, as applied in standard 4D-Var, is replaced with the use of an ensemble of non-linear model states to estimate 4-dimensional background error covariances over the assimilation time window. The computational costs for 4D-En-Var are therefore significantly reduced in comparison with standard 4D-Var and the scalability of the algorithm is improved. The flow-dependency of 4D-En-Var assimilation increments is demonstrated in single simulated observation experiments and are compared with corresponding increments
from standard 4D-Var and Hybrid 4D-Var ensemble assimilation experiments. Real observation data assimilation experiments carried out over a six weeks period show that 4D-En-Var outperforms standard 4D-Var as well at Hybrid 4D-Var ensemble data assimilation with regard to forecast quality measured by forecast verification scores.

Wed. 14:00 - 15:00 | Fuqing Zhang

Impacts and treatment of model and sampling error in ensemble based analysis and forecast systems

Wed. 15:00 - 15:20 | Chiara Piccolo

Evaluation of uncertainty in model prediction using data assimilation

Model error is a key factor in forecast uncertainty. In a realistic case, it is unlikely that model error can be represented exactly by a physically based scheme. An alternative approach is to treat model error as unknowable and use data assimilation techniques to deduce information about the model error from observations.

This paper describes this alternative approach to evaluate the effect of model error by using an ensemble of data assimilations to represent realisations of a stochastic model which contains a stochastic term defined by model errors.

Results are presented on how to set up an ensemble data assimilation system using an imperfect model such that the truth is contained within the forecast ensemble at all time with minimum spread. We show that at steady state the statistics of the analysis increments are the same as the statistics of the error growth within a data assimilation cycle and how to create a `perfect' stochastic model by setting the stochastic forcing term to a random draw from an archive of analysis increments with stationary statistics.

Wed. 15:50 - 16:10 | Florian Harnisch

Impact of ensemble perturbations provided by convective-scale ensemble data assimilation

How to derive proper initial conditions for convective-scale ensemble prediction systems (EPS) is still an open question. One common approach is to generate initial condition perturbations through dynamical downscaling of information from lower resolution models. This approach is attractive due to its simplicity and has been showing overall good results. However, by using lower resolution model information, it is not possible to represent the full spectrum of uncertainty in the initial state of the convective-scale EPS.

An alternative approach to derive proper high-resolution initial ensemble perturbations, is to apply an convective-scale ensemble data assimilation system which provides a full analysis ensemble in addition to a deterministic analysis. The derived analysis ensemble, which gives an estimate of the current theoretical analysis uncertainty, can be used as initial conditions for subsequent ensemble forecasts.

A kilometer scale ensemble data assimilation (KENDA) system for the Consortium for Small-scale Modeling (COSMO) model is currently under development at Deutscher Wetterdienst (DWD). In this study, we investigate the potential benefits of KENDA initial conditions for ensemble forecasting. A comparison of COSMO ensemble forecasts for the German domain (DE) using initial ensemble perturbations provided by KENDA and generated by the downscaling approach, highlights the improved representation of uncertainty in ensemble forecasts from the KENDA initial conditions. Further, different inflation methods of KENDA ensemble perturbations are tested to account for unrepresented error sources.

Wed. 16:10 - 16:30 | Olaf Stiller

A probabilistic tool for the cross validation of observations

Testing the quality of the received observational data is a crucial task for any data assimilation (DA) centre. Corrupted data or, generally, all data which are affected by influences which the corresponding observation operator can not handle properly should be discarded from the DA process as they may seriously diminish the quality of the analysis. Designing sensitive methods for identifying such data is therefore of great importance. While so far standard tests usually validate the observation only against the model background (i.e., the expectation value corresponding to a short term model forecast), validating them also against other observations may yield much more sensitive selection criteria. This is particularly the case for satellite radiances whose observation operators typically strongly overlap (so that observations from neighbouring channels are strongly correlated).

This work presents an extremely cost effective way for computing the conditional probability of an observation (or subset of observations) given the background and other observations. Applications for the identification of (i) outliers and (ii) breaches in data sets are outlined. More precisely, a flexible and efficient 1D Var method is described which uses the derived formulae for identifying breaches in data sets which can be hierarchically ordered according to their likeliness of being affected by influences that are not well described by the observation operator. An important example of such problems is the identification of satellite channels affected by localised sources (as, e.g., clouds or land surfaces) which might not be well described by the employed observation operators.

Thu. 09:15 - 10:00 | David Tan

Reanalysis Uncertainties and Validation/Verification

The past two decades have been a period of remarkable advances in the production of reanalysis datasets and the growth of application areas. Current developments provide many reasons to expect substantial progress to continue in coming years. Uncertainty and validation/verification remain central themes in reanalysis, and are being approached in increasingly sophisticated ways by both producers and users of reanalysis datasets. This invited talk will discuss and expand on these perspectives.

Thu. 10:30 - 11:00 | Peter Jermey

EURO4M regional reanalysis - evaluation of precipitation

EURO4M is a current EU funded project which is developing accurate high resolution climate change and monitoring data for Europe. To achieve this, for the first time, a regional reanalysis for Europe is being produced. The reanalysis is generates higher resolution datasets for Europe than was previously available from global reanalyses: 22km horizontal resolution for 1989-1992 run by SMHI and 12km for 2008-2009 by the Met Office. The quality of this state-of-the-art 12km regional reanalysis will be demonstrated by comparison with ECMWF's global ERA reanalysis, highlighting the benefits of the increased resolution. EURO4M is especially useful for investigating extreme weather events and its ability to accurately represent such events will also be demonstrated.

Thu. 11:00 - 11:30 | Christian Ohlwein

Evaluation of a COSMO-based reanalysis system for the European CORDEX domain

Within the recently founded Hans-Ertel-Centre for Weather Research (HErZ), the Climate Monitoring Branch concentrates efforts on the assessment and analysis of regional climate in Germany and Central Europe. In joint cooperation with the German Meteorological Service (DWD), a high-resolution reanalysis system based on the limited area model COSMO model has been developed. This approach comprises the assimilation of observational data using the operational nudging scheme of COSMO and is complemented by a special soil moisture analysis (SMA) and boundary conditions given by ERA?interim data. The domain matches the European CORDEX domain (EUR-11), albeit at a higher spatial resolution of approximately 6 km (COSMO-REA6). A further 2-km reanalysis for the future COSMO-DE domain is currently under development (COSMO-REA2). An important aspect in the production of the reanalysis data sets is the evaluation. In addition to the verification of standard parameters with in-situ observations, forward operators have been applied in order to verify with independent remote sensing observations. The development and evaluation of the COSMO-based reanalysis system for the CORDEX EUR-11 domain can be seen as a preparation for joint European activities on the development of an Ensemble system of regional reanalyses for Europe.

Thu. 11:50 - 12:10 | Marc Schröder

Comparison of reanalyses and satellitebased climate data records from CM SAF

EUMETSAT?s (European Organisation for the Exploitation of Meteorological Satellites) CM SAF (Satellite Application Facility on Climate Monitoring) essentially contributes to the monitoring of the climate state by provision of satellite based geophysical parameter data sets. The focus of CM SAF is on the atmospheric part of the Essential Climate Variables (ECV) defined within the Global Climate Observing System (GCOS). All publically available CM SAF products (www.cmsaf.eu/wui), their physical basis and the evaluation results are subject to an external review. As the majority of CM SAF products have global coverage the evaluation of CM SAF CDRs also utilises data from reanalysis.

Two regional reanalysis data sets for Europe have recently become available through the EURO4M project (www.euro4m.eu). Both reanalysis data sets are derived from regional model simulations using ERA-Interim as boundary conditions and modern data assimilation techniques on the regional domain. The CM SAF data records of surface solar radiation, cloud coverage, and integrated water vapour have been used to assess the quality of these newly available reanalysis data sets.

In a Joint Letter from GCOS and the World Climate Research Programme (WCRP) the general need for coordinated international assessments of climate products was formulated. The GEWEX Data and Assessments Panel (GDAP) has initiated a Water Vapor Assessment in 2011, further on referred to as G-VAP (www.gewex-vap.org), which is co-chaired by CM SAF. Major elements of G-VAP are inter-comparisons and comparisons against in situ observations as well as against ground-based products and an analysis of the degree of stability of the individual data records. Also, data from several reanalyses is considered in these activities.

In this presentation, several results from the comparison of CM SAF CDRs and data from reanalysis will be presented. A focus will be on temporal stability, anomalies and the spatial distribution of observed biases. Also results from G-VAP will be shown, with a focus on observed inconsistencies among the long-term satellite data records and reanalysis as observed by the (inter-)comparisons and the stability analysis. We conclude that large progress in terms of recovery, coverage and quality has been made over the past years. However, significant discrepancies still exist which need to be understood and removed.

Thu. 14:00 - 14:40 | Jan Douša

Overview of GNSS Data Processing Methods and Data Quality

Global Navigation Satellite System (GNSS) signal is propagated from a satellite to a receiver on the surface through the atmosphere. The GNSS signal path delay due to the neutral atmosphere, which is independent of a transmitted signal frequency, needs to be adjusted in any high-accurate GNSS application together with other geodetic parameters. Adequately precise information is not available from other source or a specific instrumentation, e.g. radiometers or radio sounding, is too expensive and impractical for this purpose. While the tropospheric path delay is considered as a noise in geodetic applications, it was found as useful information in other applications, such as meteorology or climatology. During last decades GNSS proved to be a valuable technique for the water vapour monitoring if relevant geodetic parameters (receiver and satellite positions) as well as all other systematic errors (biases, etc.) are precisely estimated or modelled. In such case, the effect of the GNSS signal propagation caused by the troposphere can be precisely estimated according to the requirements of the numerical weather forecasting applications in terms of accuracy, timeliness, etc. Since ninetieth, various methods of near real-time troposphere monitoring in support of numerical weather forecasting have been developed using ground-based GNSS permanent stations. This presentation gives background information on GNSS and its observed signals, it provides a brief description of the existing processing methods together with requirements of precise products and models, it summarizes other aspects related to the provision of GNSS products in near real-time including all necessary processing steps and, finally, it demonstrates GNSS tropospheric product quality.

Thu. 14:40 - 15:20 | G.V. Bennitt

Overview of GNSS Data Assimilation at the UK Met Office

Since the concept of GNSS Meteorology was first introduced in the early 1990s, numerous studies have set out to exploit signals from GNSS satellites in meteorology. The first operational assimilation of Zenith Total Delay (ZTD) measured at Ground-based GNSS receivers started more than a decade later in
2007. The Met Office was one of the first NWP centres to assimilate Ground-based GNSS ZTD observations operationally, and has been continuing to refine its assimilation methods since that time. The methods used by the Met Office for ZTD assimilation, the results of recent impact studies, and the results of some recent studies to diagnose error correlations will be presented. Some considerations for ZTD assimilation in the future will also be discussed.

Thu. 15:20 - 15:40 | Jean-Francois Mahfouf

Overview of GNSS Data Assimilation at Meteo France

The Zenith Total Delay (ZTD) derived from Global Navigation Satellite Systems (GNSS) observations is presently being assimilated into many state-of-the-art Numerical Weather Prediction (NWP) models worldwide. This helps to improve the knowledge of the initial state of the atmosphere and the subsequent forecasts. The convective scale NWP model AROME is operational at Météo-France since December 2008. The AROME model has a resolution of 2.5 km and uses the three dimensional variational (3D-Var) data assimilation scheme with a Rapid Update Cycle (RUC) of 3 hours.
This study presents a recent assessment of the impact of assimilation of the GNSS derived ZTD observations into the AROME 3D-Var model. Two data assimilation experiments have been performed for a recent summer period of July 17, 2013 to August 20, 2013. The first experiment uses the ZTD from the stations and analysis centers available in real time through the E-GVAP. In the second experiment, additional stations processed by the University of Luxembourg have been added to the observations from E-GVAP. A third experiment without the assimilation of any GNSS ZTD observations has been performed to serve as a baseline for the first two experiments and to provide an impact assessment of GNSS ZTD data assimilation in the AROME model. From the output of these three experiments, various parameters have been extracted and statistics for the comparisons between those have been calculated. The impact assessment has been carried out in two parts i.e. studying the impact on the model analysis and studying the impact on model forecasts.

Thu. 16:00 - 16:20 | Takuya Kawabata

GPS Slant Total Delay Assimilation with a Storm Scale 4D-Var on an MCS Event

A method to assimilate slant total delays derived from Global Positioning System (GPS) data using the four-dimensional variational data assimilation technique was developed and applied to a line-shaped local heavy rainfall event that formed on 19 August 2009 over Okinawa Island, Japan.
First, We conducted a high-resolution numerical experiment using the Japan Meteorological Agency non-hydrostatic model with a 2-km horizontal grid spacing (NODA). And then data assimilation experiments with GPS observations (GPS zenith total delay (GPS-ZTD), GPS precipitable water vapor (GPS-PWV), and GPS slant total delay (GPS-STD)) at the same resolution. Compared with NODA, assimilation of GPS-ZTD and GPS-PWV data slightly improves the timing of the subsequent rainband initiation. However, the GPS-STD assimilation significantly improved the water vapor and temperature fields over a wide area and yielded a clearly improved forecast in terms of both rainfall timing and intensity.

Thu. 16:20 - 17:00 | Michael Bender

GNSS Data Assimilation and GNSS Tomography for Global and Regional Models

The delay of the GNSS signals provides information about the atmospheric state. Zenith total delays (ZTDs) and the corresponding integrated water vapor (IWV) are widely used in atmosphere sounding and data assimilation. The spatial information provided by slant total delays (STDs) is a subject of current research. Ground based GNSS atmosphere sounding develops in many directions: New satellites will become available, the GNSS station networks are continuously expanded and the GNSS processing strategies are improved. Furthermore, there is a transition from near real-time processing with delays of about one hour to real-time streams with delays of some seconds.

This talk will focus on the information provided by STD observations and show some results from two different strategies used to obtain spatially resolved atmospheric fields: GNSS tomography and assimilation of STDs into global to convective scale NWP. Tomographic reconstruction techniques take the STD observations as input and try to invert these data in order to obtain 3D fields of the humidity or the refractivity. This approach is mathematically demanding as the distribution of GNSS satellites and ground stations is rather inhomogeneous and the inversion algorithm has to deal with incomplete, highly variable data. Results obtained with the MART algorithm will be shown and the impact of an increasing number of GNSS satellites will be discussed. Future developments of advanced inversion algorithms or real-time tomography will be mentioned.

The DWD is currently developing a STD/ZTD assimilation operator which works with the global model ICON as well as the regional COSMO model. A common interface was designed in order to link the operator to the 3D¬Var assimilation of ICON and the LETKF of COSMO. A STD observation operator needs to consider the ray bending in the atmosphere. Therefore a ray tracer was developed which solves the variational problem defined by Fermat's principle and estimates the bended signal path through the atmosphere. The design of the operator and the ray tracer will be discussed. Currently, STD observations for Germany are available from the GFZ in Potsdam. These data are used to test the operator and the GNSS assimilation. A GNSS monitoring system required for bias correction and quality control is under development and first results will be shown.

Thu. 17:00 - 17:30 | Henrik Vedel

E-GVAP