In this study, we examine the impact of atmospheric motion vectors (AMV) derived using imagery from the MISR (Multi-angle Imaging SpectroRadiometer) instrument flown onboard the EOS-Terra satellite. The algorithms for the MISR Level 2 Cloud product used in this study retrieve both cloud height and horizontal motion from the apparent displacement due to parallax and movement of cloud features in visible channel (670nm) camera views during a single overpass. Retrievals are redundantly derived from images from banks of four cameras each pointing forward and aft, and then synthesized into a final height-resolved AMV. AMVs derived from the MISR instrument have several unique strengths that are especially relevant for NWP applications. First, the integrated height retrievals are insensitive to radiometric calibration or atmospheric temperature profiles, giving a more accurate height assignment for the AMVs. Second, the cameras capture motion over a 200 second interval, providing an effective 17.6 km gridded resolution. Finally, MISR gives good global coverage up to 85° (depending upon the season (sunlight)), much further poleward than geostationary AMVs.

The MISR winds were assimilated using the global atmospheric prediction system developed by the Naval Research Laboratory. This system is composed of NAVDAS-AR (NRL Atmospheric Variational Data Assimilation System—Accelerated Representer), and the newly-operational Navy Global Environment Model (NAVGEM). The experimental configuration was designed to closely match the FNMOC T359L50 operational configuration. The MISR assimilation runs were initialized at 00 UTC 20 October 2012, 5-day forecasts were initialized from the 00, 06, 12, 18 UTC analyses, and the entire system was run through 00 UTC 15 November 2012. For the initial assimilation test, the MISR wind super-observation generation, quality control and data selection procedures were patterned after those used for geostationary and polar-orbiter AMVs. MISR heights were converted to pressure by horizontally and vertically interpolating pressure to the observed height from the model background geopotential height field on pressure surfaces, the same process used at NRL to convert height to pressure for PIBAL and airborne lidar wind data. The MISR observation errors were identical to those used for other AMVs.

The adjoint-based observation impacts were computed for each 6-hr update cycle, using a global tropospheric moist total energy error norm. For NAVDAS-AR/NAVGEM, Atmospheric Motion Vectors from geostationary satellites dominate the reduction in the 24-hr forecast error. Even so, the MISR AMVs were ranked as seventh most important on a per-observation basis. We plan to further explore MISR wind assimilation through a series of experiments designed to enhance the extraction of information from the MISR winds, and to better understand the complementary nature of the MISR winds.
Investigating the Impact of pre-GPM Microwave Precipitation Observations in the Goddard WRF Ensemble Data Assimilation System

Philippe Chambon\textsuperscript{a}, Sara Q. Zhang\textsuperscript{b}, Arthur Y. Hou\textsuperscript{b}, Milija Zupanski\textsuperscript{c} and Samson H. Cheung\textsuperscript{d}

\textsuperscript{a} CNRM-GAME, Météo-France and CNRS, Toulouse, France, philippe.chambon@meteo.fr, \textsuperscript{b} Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, MD, USA, \textsuperscript{c} Colorado State University, Fort Collins, CO, USA, \textsuperscript{d} University of California, Davis, CA, USA

In recent decades, the availability of satellite observations has greatly increased, in particular passive microwave observations on precipitation processes. Because rainfall has large variability and short predictability time, frequent and broad data coverage is crucial to assimilation of precipitation data to improve precipitation analyses and forecasts in NWP system. Indeed, the forthcoming GPM (Global Precipitation Measurement) program will provide more than fifteen overpasses per day in the mid-latitudes thanks to a constellation of observing systems. The assimilation of precipitation-affected radiances into numerical forecast models has shown promising potential in improving atmospheric analyses and forecasts. In the meantime it also raises new challenges to data assimilation systems. In order to effectively use these observations, a data assimilation system needs to have a forecast error covariance capturing temporal and spatial variability of precipitation and clouds, an observation operator adequately representing non-linear microphysics and radiative transfer in presence of clouds and precipitation.

We present a data impact study on the assimilation of microwave radiance observations in precipitating areas using Goddard WRF ensemble data assimilation system (Goddard WRF-EDAS). A series of assimilation experiments are carried out using a pre-GPM constellation in a WRF 9 km grid-spacing domain in Western Europe (SSMIS/DMSP-F16, -F17, -F18; AMSRE/E/AQUA; MHS/NOAA-18, -19 and Metop-A). A case study of storms, which occurred over France in September 2010, is used to illustrate the analysis sensitivity to precipitation-affected observation errors and the flow-dependent background error covariance of hydrometeors. A bias correction scheme is developed based on the statistics of radiance innovations in rainy areas. Observation system experiments (OSE) are configured as a control and a set of experiments using pre-GPM precipitation data with varied frequency of data coverage in different lengths of assimilation window. Results show that the assimilation of multiple-instrument radiances in precipitating areas has a positive impact on the accumulated rain forecasts verified by ground-based radar rain estimates.
Assimilation of Attenuated Reflectivity Data from X-band Network Radars Using Ensemble Kalman Filter

Jing Cheng and Ming Xue

School of Meteorology and Center for Analysis and Prediction of Storms
University of Oklahoma, Norman, Oklahoma, USA
jcheng@ou.edu

To use reflectivity data from X-band radars for quantitative precipitation estimation and storm-scale data assimilation, the effect of attenuation must be properly accounted for. Traditional approaches try to make correction to the attenuated reflectivity first before using the data. An alternative, theoretically more attractive approach build the attenuation effect into the observation operator of reflectivity within a data assimilation system, such as an ensemble Kalman filter (EnKF) [1]; such a system directly assimilates the attenuated reflectivity and takes advantage of the power of EnKF in microphysical state estimation for potentially more accurate solution.

This study first test the approach for the CASA (Center for Collaborative Adaptive Sensing of the Atmosphere) X-band radar network configuration through observing system simulation experiments (OSSE) for a quasi-linear convective system that has more significant attenuation than isolated storms. To avoid the problem of potentially giving too much trust to fully attenuated reflectivity, an analytical echo-intensity-dependent model for the observation error (AEM) is developed and is found to improve the performance of the filter. Sensitivity experiments are designed to examine the effectiveness of AEM by introducing multiple sources of observation errors into the simulated observations. The performance of such an approach in the presence of resolution-induced model error is also evaluated and good results are obtained. This system with build-in attenuation correction is then applied, for the first time, to a real case, using data from the X-band radars from the CASA Oklahoma testbed. For the 24 May 2011 Chickasaw, Oklahoma, tornado case, the attenuation correction procedure is found to be very effective – the analyses obtained using attenuated data are better than those obtained using pre-corrected data when all the values of reflectivity observations are assimilated. The effectiveness of the procedure is further examined by comparing deterministic and ensemble forecasts.

References
Improving the Assimilation of GPS Radio Occultation Observations in the Lower Troposphere

L. Cucurull\textsuperscript{a} and R. J. Purser \textsuperscript{b}

\textsuperscript{a} NOAA/OAR/ESRL/GSD \& CIRES, US, Lidia.Cucurull@noaa.gov. \textsuperscript{b} NOAA/NWS/NCEP/EMC \& IMSG, US.

The National Centers for Environmental Prediction (NCEP) have been assimilating Global Positioning System (GPS) Radio Occultation (RO) observations in its global data assimilation system since 2006. The benefits of incorporating RO observations into the observing system have been demonstrated worldwide, proving that RO data contain very important information on the thermodynamic state of the atmosphere.

Despite the fact that GPS RO technology is a promising tool in recovering the Planetary Boundary Layer (PBL) structure and significant advances have been seen in the GPS RO field during the past decade, there are still some serious issues that affect the assimilation of these observations in the lower moist tropical troposphere. Indeed, Numerical Weather Prediction (NWP) centers using GPS RO data are rejecting most GPS RO observations at and below the PBL height, significantly limiting the potential benefits of this data type to improve weather forecasting in the lower troposphere. The reasons for the rejection of these observations are a combination of quality issues that affect retrievals in the lower troposphere and several challenges existing in the data assimilation algorithms. To address this problem, a methodology has been developed to enable the assimilation of GPS RO data to be extended to the lower moist troposphere.

In particular, the limitations associated with so-called super-refraction conditions, which have hitherto prevented NCEP’s forward operator NBAM (NCEP’s bending angle method) from applying to the moist lower troposphere, are partially eliminated by a reformulation that has no adverse effects at higher altitudes. Super-refraction, which refers to vertical gradients of refractivity strong enough to cause the ray curvature to exceed the local geopotential curvature, occur frequently at the top of low-latitude maritime boundary layers. While GPS RO rays coming close to tangency with these layers cannot participate in the assimilation, those that penetrate more steeply to greater depths offer valid opportunities for assimilating thermodynamic quantities at these meteorologically important levels. However, the more erratically distributed errors inherent in bending angle measurements for these deeper-penetrating rays need especially to be analyzed and interpreted carefully in order that an appropriately tuned adaptation of the nonlinear quality control technique can ensure that, through the proper attribution of relative weighting, the assimilation of information from them continues to be acquired in a robust and approximately optimal way.

During this talk, the characteristics and initial performance of NCEP’s advanced bending angle method (NABAM) over NBAM will be discussed. In addition, the use of a nonlinear quality control methodology for the assimilation of bending angle observations will be presented.
The impact of assimilating satellite-derived winds, airborne Doppler radial velocity and dropsonde data on the analysis and prediction of Hurricane Earl (2010) using an ensemble Kalman filter

Jili Dong¹ and Ming Xue¹,²

¹Center for Analysis and Prediction of Storms and ²School of Meteorology
University of Oklahoma, Norman Oklahoma 73072

Jldong@ou.edu

Satellite-derived rapid-scan winds or atmospheric motion vectors (AMVs), airborne Doppler radar radial velocity (Vr) and dropsonde observations are assimilated for rapidly intensifying Hurricane Earl (2010) using the ARPS ensemble Kalman filter (EnKF) system at cloud-permitting 4 km grid spacing while the WRF ARW model is used for the forecasting. The enhanced satellite-derived winds from the Cooperative Institute for Meteorological Satellite Studies (CIMSS) during the Pre-Depression Investigation of Cloud-Systems in the Tropics (PREDICT) experiment can provide the circulation information at higher spatial and temporal resolutions than the routine operational AMVs. A 40-member ensemble is created from the operational global ensemble forecast system. The assimilation of Vr data improves the analysis of the inner core axisymmetric circulation and warm core thermal structures within a deep, intense vortex while the impact of assimilating dropsonde data is mostly in the lower troposphere. The assimilation of Vr and dropsonde also improves the 36 hours intensity forecast. The impact from the assimilation of satellite-derived wind on the track and intensity forecast is discussed. Multiple microphysics (MP) and planetary boundary layer (PBL) parameterization schemes are employed in the ensemble to partly account for model uncertainty and the results are compared with experiments using a single suite of physics.

References:


Position error correction methods in data assimilation for weather forecasts have received in the recent past increased attention. DA algorithms usually employed in Limited Area NWP operational systems (e.g. 3DVar) cannot handle properly this kind of errors. Hence the importance of bringing in these environments efficient techniques that can improve on the current situation. In this work, the implementation of the Field Alignment method [1] in a state-of-the-art of one of such systems is presented. HARMONIE is the result of the collaboration in the NWP field of several European NMHS and is already being used in some of them to provide operational forecasting centers with short range weather predictions at a spatial resolution of the order of 2 Km. The tests on the method carried out so far have included radial Doppler wind and reflectivity data from six C-band operational weather radars of the Spanish network. These tests are giving encouraging results. Verification with the own radar data indicates a positive impact for all ranges and that it can last for longer than three hours in some cases. These verifications do not show severe spin-up noise. Among the problems found in the course of this development, the difficulty of having to adjust to the constraints imposed by the system’s design is certainly one to mention. Several variants of the use of the Field Alignment method and more tests with radar data are underway in order to gain a more complete evaluation of the possibilities of the technique in an operational framework.

References
*Physica D*, **230**, 127-145
Impacts of Inter-Channel Interference on the Use of AIRS in Data Assimilation

Wei Gu\textsuperscript{a}, and Ricardo Todling\textsuperscript{b}

\textsuperscript{a} Science System and Applications, Inc., USA, wei.gu@nasa.gov. \textsuperscript{b} Global Modeling and Assimilation Office, GSFC, NASA, USA.

A posteriori diagnostic studies indicate that considerable inter-channel observation error correlations are present in certain wavelength bands in the high-spectral-resolution infrared sounders such as AIRS and IASI (Garand et al., 2007, Bormann and Bauer 2010, Bormann et al 2010). Because of the lack of knowledge of the true error correlation structure in these data and the complexity to account for correlations in the underlying analysis system, the errors between different channels are treated as uncorrelated and resulting inter-channel interferences could make some observations be assimilated improperly. An approach to account for this simplification is to inflate the observation error variances assigned to the data. The amount of inflation needs to be determined and needs to be such that the corresponding observation information content is not severely degraded, enforcing inter-channel interferences to remain low which would allow observations from high-spectral-resolution instruments such as AIRS and IASI to be properly assimilated.

A 1-dimensional diagnostic tool based on estimates of the so-called background error variance reduction is being combined with the Degrees of Freedom for Signal (DFS) diagnostic to allow investigating more closely how best to assimilate AIRS observations with the GMAO 3DVar system. The idea is to choose proper observation error inflation parameters to reduce inter-channel interference from AIRS, especially when it comes to the long-wave surface temperature and water vapor sensitive channels.

References
The Concordiasi Campaign over Antarctica: Inter-model Monitoring and Impact on the Assimilation.

Vincent Guidard\textsuperscript{a}, Florence Rabier\textsuperscript{a}, Nathalie Saint-Ramonda, Jean-Noël Thépaut\textsuperscript{b}, Carla Cardinali\textsuperscript{b}, Rolf Langland\textsuperscript{c}, Andrew Tangborn\textsuperscript{d}, Albert Hertzog\textsuperscript{e} and Philippe Cocquerez\textsuperscript{f}

\textsuperscript{a}CNRM-GAME, Météo-France and CNRS, France, vincent.guidard@meteo.fr, \textsuperscript{b}ECMWF, UK, \textsuperscript{c}NRL, Monterey, \textsuperscript{d}GMAO, NASA, USA, \textsuperscript{e}LMD, France, \textsuperscript{f}CNES, France.

The Concordiasi project is a multi-annual field campaign over Antarctica. The main goal is to provide validation data to improve the usage of polar-orbiting satellite data over Antarctica, in particular IASI radiances. The other areas of interest are the fine scale meteorological and climatic studies of the Antarctic plateau, the study of the influence of better polar area predictions over lower latitudes and over the ozone simulation, together with the monitoring of the polar vortex at the end of winter, thanks to additional stratospheric measurements [1]. In particular, the austral spring-summer 2010 campaign deployed CNES superpressure balloons, most of which were fitted with NCAR dropsounding facility, in addition to LMD in-situ measurement in the gondola.

As the data were distributed in near real time on the GTS, many Numerical Weather Prediction Centres assimilated them in their operational global models. A first part of this paper will describe the compared monitoring of the field campaign measurements between the centres. Some common features highlight some common biases in the models, among other conclusions.

A second part of this paper deals with impact studies. First, using data denial experiment, the direct impact of the special measurements of the campaign is evaluated in a specifically-tuned global model ARPEGE. Then forecast sensitivity to observations (FSO) have been computed at different centres. The FSO results will then be compared with data denial experiment results.

As a conclusion, the outcomes presented in this paper will provide us with some assessment of model quality and with conclusions on the data impact, through the assimilation, over Antarctica.

References
Experimental Assimilation of Spaceborne Cloud Radar and Lidar Observations at ECMWF

Marta Janisková, Sabatino Di Michele, and Edouard Martins

European Centre for Medium-Range Weather Forecast, UK, Email address of the corresponding author: marta.janiskova@ecmwf.int

Observations providing three-dimensional information on clouds from spaceborne active instruments as CloudSat and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) are already available and new missions, such as EarthCARE (Earth Clouds, Aerosols and Radiation Explorer) should appear in the near future. The challenge is to assimilate these novel sources of data into a numerical weather prediction (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 spaceborne cloud radar and lidar observations for monitoring and assimilation.

The presentation will summarise the developments and experimentations done to make use of these new observations in the ECMWF system. First, the forward operator used to transform model output into the equivalent radar and lidar observations will be briefly described together with other important components of the assimilation system (such as definition of observation errors, quality control and bias correction). Then, the results from assimilation experiments using variational technique to assimilate cloud observations from CloudSat and CALIPSO (separately or in combination) will be presented.
Sensitivity of Assimilating GOES Cloud Water Path Retrievals to Model Cloud Microphysics

Thomas A. Jones\textsuperscript{a}, D. J. Stensrud\textsuperscript{b}, P. Minnis\textsuperscript{c}, and R. Palikonda\textsuperscript{d}

\textit{a. Cooperative Institute for Mesoscale Meteorological Studies}
University of Oklahoma
Thomas.Jones@noaa.gov

\textit{b. NOAA/OAR/National Severe Storms Laboratory, Norman, OK}

\textit{c. NASA Langley Research Center, Hampton, VA}


Assimilating retrieved cloud properties from satellite data into storm-scale models has to date received limited attention in the research community despite its potential to provide a wide array of information to a model analysis. Retrievals currently available include cloud water path (CWP), which represents the amount of cloud water and cloud ice present in an integrated column and cloud top (base) heights. Retrieval algorithms have been developed to derive these products from operational GOES Imager data with a spatial resolution of up to 4 km at 15 minute intervals.

Jones et al. (2013) developed a new forward operator designed to assimilate CWP retrievals through the Data Assimilation Research Testbed (DART) software using an Ensemble Kalman Filter (EnKF) approach. The new CWP forward operator combines the satellite cloud height information with the WRF generated cloud hydrometeor variables to determine where in the atmospheric column and how much to adjust the CWP to match the observation. Testing of this forward operator within a convection allowing model using a case study occurring on 10 May 2010 in Oklahoma and Kansas showed positive impacts on both the location of ongoing convection in the model and in the reduction of spurious convection generated by the model when no satellite data was assimilated.

Since CWP is directly related to the cloud hydrometeor variables in the model analysis, it follows that the assimilation will be highly sensitive to the cloud microphysics scheme selected. To test this hypothesis, experiments using idealized convection in addition to real data are conducted for a variety of cloud microphysics schemes. In both cases, the more advanced schemes tended to perform better compared to more traditional schemes. In particular, the concentrations of frozen hydrometeors (ice, snow, graupel, and hail) were particularly sensitive to the scheme used by an experiment. These results emphasize the importance of using the right cloud microphysics scheme when assimilating cloud property retrievals or any other satellite data within cloudy regions.

Future GOES-R retrievals will improve both the spatial and temporal resolution as well as provide more detailed information on multiple cloud layers and liquid vs. frozen cloud phases. As a result, the positive impacts found when using both simulated and real retrievals based on current data should only increase as GOES-R data becomes available in the future.

References

Assimilating Satellite Observations of Precipitation into the NCEP NWP Models

Min-Jeong Kim\textsuperscript{a,b}, Brad Ferrier\textsuperscript{a}, Yanqiu Zhu\textsuperscript{a}, Emily Liu\textsuperscript{a}, Daryl Kleist\textsuperscript{a}, Andrew Collard\textsuperscript{a}, and John Derber\textsuperscript{a}

\textsuperscript{a} NOAA/NCEP/EMC, \textsuperscript{b} CIRA, Colorado State University, USA

Min-Jeong.Kim@noaa.gov

Currently, the majority of satellite data affected by clouds and precipitation are discarded in the NOAA NCEP operational data assimilation systems. This is mainly due to difficulties involved in the forward modeling of radiance affected by clouds and precipitation as well as defining observation and background errors.

There has been research activities aimed at developing cloud affected microwave radiance data assimilation components in the NCEP operational numerical weather forecast systems. The initial capability to assimilate Advanced Microwave Sounding Unit (AMSU)-A cloudy radiance data in non-precipitating sky condition has been developed in NCEP data assimilation systems. These recently developed components are currently being tested in NCEP global and regional analysis systems.

To extend the application of current cloudy radiance data assimilation system to precipitating sky condition, this paper revisits observation operators, observation error models, bias corrections, quality controls, state/control vectors and background errors in NCEP Global Data Assimilation System (GDAS). For example, the observation operator to simulate radiance data in the GSI are extended to include various precipitation types of hydrometeors affected radiance data. GFS moisture physics modified with WRF NMM model microphysics schemes are applied to GFS 06hr forecast cloud mixing ratio profiles to calculate first guess (liquid and/or frozen precipitation profiles. These profiles are employed in the CRTM to calculate radiance and sensitivity of microwave radiance data to clouds and precipitation profiles.

Microwave radiance data in precipitating cloudy sky conditions include strong scattering signal that makes optimization in assimilation systems more complicated because of difficulties in forward calculations and observation error estimations. Therefore, the uncertainty in the Community Radiative Transfer Model (CRTM) especially in precipitating sky conditions with strong scattering signals are examined to be considered in observation error estimations. Finally, the potential impacts of assimilating microwave radiance data in precipitating sky condition on NCEP global NWP forecasts are discussed in this presentation.
Use of Adjoint Methods for Tuning of Observation Error in the Navy Global Atmospheric Forecast System

Rolf H. Langland\textsuperscript{a}, and Dacian N. Daescu\textsuperscript{b}

\textsuperscript{a} Naval Research Laboratory, Marine Meteorology Division, Monterey, California, U.S.A., rolflangland@nrlmry.navy.mil, \textsuperscript{b} Portland State University, Portland, Oregon, U.S.A.

This talk describes a new adjoint-based method for tuning specified observation error variance ($s_i^o$) in atmospheric data assimilation and the results of first experimental testing. The study uses the Navy Global Environmental Forecast System (NAVGEM) and its 4d-Var data assimilation procedure (NAVDAS-AR) The practical objective of the study is to improve (through adjustment of $s_i^o$) the assimilation of satellite radiance observations (including AMSU-A, IASI, and AIRS) in NAVDAS-AR and thereby increase the accuracy of NAVDAS-AR atmospheric analyses (Langland et al. 2008) and NAVGEM forecasts.

Here, $s_i^o$ is a scalar coefficient defined by assumptions of observation error. An additional scalar coefficient, $s_i^b$ defines the assumed error of the background (in this case a 6h prior forecast) at an observation location. Together, $s_i^o$ and $s_i^b$ determine the weight given in NAVDAS-AR to the information from an assimilated observation ($i$). In our experiments the usual value of $s_i^o$ is adjusted using sensitivity information provided by adjoint versions of the forecast model and data assimilation procedure. A sensitivity gradient vector, $\partial e / \partial s_i^o$, is defined as described in Daescu and Langland (2013). The forecast response function ($e$) is a scalar measure (norm) of energy-weighted 24h forecast error. Note that that unlike other methods for tuning $s_i^o$ (for example, that of Desroziers and Ivanov 2001) in this method the adjustments to $s_i^o$ are defined specifically to reduce a metric of forecast error.

The gradient $\partial e / \partial s_i^o$ provides sensitivity information for every assimilated observation. However, at present, $\partial e / \partial s_i^o$ indicates only whether the value of $s_i^o$ should be increased or decreased and not a specific “optimal” value for $s_i^o$. Thus, our tuning process involves two steps: i) identification of whether $s_i^o$ should be increased or decreased for a particular radiance channel and ii) an estimate of how much $s_i^o$ should be changed. Note that in NAVDAS-AR, $s_i^o$ is a constant over the entire global domain for each specific radiance channel.

First experiments using this method include a reduction (0.5) of $s_i^o$ for AMSU-A channels 5-8, and increases (2.0) for a subset of IASI channels and AIRS observations. We are able to demonstrate that these changes to $s_i^o$: i) bring the NAVDAS-AR analysis closer to the ECMWF analysis, ii) reduce the 24h forecast error norm in NAVGEM, and iii) reduce root mean square error of 500hPa height forecasts.

REFERENCES


Using Simulated Atmospheric Motion Vector Wind Retrievals from NWP Radiances to Characterize Height Assignment Errors

Peter Lean\textsuperscript{a}, Graeme Kelly\textsuperscript{b}, Stefano Migliorini\textsuperscript{a,c}

\textsuperscript{a}Department of Meteorology, University of Reading, UK, \texttt{p.w.lean@reading.ac.uk}, \textsuperscript{b}Met Office, UK, \textsuperscript{c}ECMWF, UK.

Atmospheric Motion Vectors (AMVs) are wind retrievals produced by tracking coherent features between consecutive satellite images. The apparent motion of the feature provides the wind vector, which is then assigned to a certain height based on the estimated height of the tracked feature. Height assignment errors are widely considered to be one of the primary sources of error in AMV wind retrievals, limiting their impact when assimilated into NWP models.

Simulation studies, whereby synthetic Atmospheric Motion Vector retrievals are generated from high resolution NWP model radiances, provide a useful tool to help understand and characterize these errors.

In this presentation we present results from an investigation of height assignment errors using the Met Office 1.5km grid length UKV model to generate synthetic AMVs using the NWCSAF package. Statistics of cloud top height errors from the NWCSAF cloud products are calculated through a comparison against the model ‘truth’ cloud condensate profiles during a month long trial period.

Results indicate that biases in the assigned cloud top heights depend strongly on the diagnosed cloud type and cloud height. The feasibility of bias correction of the cloud top height product to reduce systematic height assignment errors in AMVs will be discussed.
Assimilation of Dual-Polarimetric Radar Observations with WRF 3DVAR and its Impact

Xuanli Li\textsuperscript{a}, John Mecikalski\textsuperscript{a}, Traci Fehnel\textsuperscript{a}, and Derek Posselt\textsuperscript{b}

\textsuperscript{a} Department of Atmospheric Science, University of Alabama in Huntsville, Huntsville, AL, USA
\textsuperscript{b} Atmospheric Science Department, University of Michigan, Ann Arbor, MI, USA

xuanli@nsstc.uah.edu, Atmospheric Science Department, University of Michigan, Ann Arbor, MI, USA

Owing to the significant progresses in the high-resolution numerical modeling and data assimilation techniques, the numerical prediction of severe weather has been improved substantially. However, it remains a big challenge to predict accurately the evolution of convective events, especially on the storm scale and hence, storm-related quantitative precipitation forecast (QPF). Studies have shown that radar data assimilation can help with short-term prediction of convective weather by providing more accurate initial condition.

Dual-polarimetric (dual-pol) radar typically transmits both horizontally and vertically polarized radio wave pulses. From the two different reflected power returns, information on the type, shape, size, and orientation of cloud and precipitation microphysical particles are obtained, more accurate measurement of liquid and solid cloud and precipitation particles can be provided. The motivation for this research is centered around the upgrade of the current NWS WSR-88D radar network to include dual-pol capabilities, as started in 2011 and to be completed soon. The dual-pol radar network will cover the whole continental US, and therefore our research should have broad-reaching impacts. The assimilation of dual-pol radar data is however, challenging work as few guidelines have been provided on dual-pol radar data assimilation research. It is our goal to examine how to best use dual-pol radar data to improve forecast of severe storm and forecast initialization.

Our presentation will highlight our recent work on assimilating dual-pol radar data for real case storms. In our study, high-resolution Weather Research and Forecasting (WRF) model and its 3-Dimensional Variational (3DVAR) data assimilation system are used for real convective storms. Our recent research explores the use of the horizontal reflectivity ($Z_H$), differential reflectivity ($Z_{DR}$), specific differential phase ($K_{DP}$), and radial velocity (VR) data for initializing convective storms and snowfall events, with a significant focus being on an improved representation of ice hydrometeors. Our previous research indicated that the use of $Z_{DR}$ can bring additional benefit into the hydrometeor fields than the use of $Z_H$ only. Furthermore, the combination of $K_{DP}$ and $Z_{DR}$ data provide the best initialization for precipitation particles with warm-rain radar data assimilation. Our ongoing work includes the development of an ice microphysics processes scheme within the 3DVAR assimilation procedure. The ice processes can help to describe the ice particles more precisely at and above the melting layer.

In addition to forward model development, high-resolution ($\leq 1$ km) WRF model simulations and convective scale data assimilation experiments with WRF 3DVAR system will be discussed, emphasizing both warm rain and ice microphysical processes. Further details of the methodology of data assimilation, the influences of different dual-pol variables on model initial condition and on the short-term prediction of precipitation, and additional results from our ongoing work on the assimilation of dual-pol radar data, will also be presented at the symposium.
ASSIMILATION of GNSS RADIO OCCULTATION OBSERVATIONS
at GRAPES

Yan LIU\textsuperscript{a}, Jishan XUE\textsuperscript{b}

\textsuperscript{a}Numerical Weather Prediction Center, China Meteorological Administration, China, Email:liuyan@cma.gov.cn,
\textsuperscript{b}Chinese Academy of Meteorological Sciences, China Meteorological Administration, China

The radio occultation (RO) sounding technique that uses signal transmitted by Global Navigation Satellite System (GNSS) has evolved as an important global observing technology. The assimilation of GNSS RO refractivity has been implemented in GRAPES (Global and Regional Assimilation Prediction System) of China since 2009. The results of the assimilation experiments have showed that the GNSS RO measurements provide good geopotential height information not only in the upper troposphere and lower stratosphere but also in the lower troposphere, particularly in the southern hemisphere and the ocean, which produce a clear improvement in the RMS and Bias fit to radiosonde data at GRAPES assimilation system. The accuracy of analyzed humidity is also improved. The forecast impact experiments are also shown to have a positive impact on short- and medium-range forecast after assimilating GNSS RO data, which is a beneficial, persisting and cumulative effect. Recently we have updated the GNSS RO refractivity observation operator in the new GRAPES-Var system which has the same coordinator and variables definition to the GRAPES forecast model. During this paper the quality control of GNSS RO data in the pre-processing procedure, observation error characterization, and the forward operator and associated tangent linear and adjoint model in the new GRAPES-Var system will be presented, including the results in a 1D-Var system.
Targeted Observations for Improving Numerical Weather Prediction: Review and Recommendations

Sharanya J Majumdar

Rosenstiel School of Marine and Atmospheric Science, University of Miami, USA.
smajumdar@rsmas.miami.edu

“Targeted observations” refers to the selection of additional, specially chosen observations to be assimilated into operational numerical weather prediction models. Observation locations are chosen in order to improve forecasts of high-impact weather events such as winter storms and tropical cyclones. Examples of targeted observations include dropwindsondes launched from aircraft, additional rawinsonde ascents, and the inclusion of enhanced regular satellite observations (such as radiances or winds) that may normally be excluded from data assimilation due to routine thinning or quality control procedures. As a consequence of many field campaigns worldwide during the past 15 years, advancements have been made in the development of objective strategies for targeting observations, and in quantitative evaluations of the impact of assimilating these extra observations on numerical weather predictions. The successes and shortcomings of these efforts are summarized in this presentation. Based primarily on a comprehensive review by the THORPEX Data Assimilation and Observing Systems Working Group [1], recommendations are made to the community for the use of targeted observations in the future.

References
The Assimilation of Cloud-Affected Infrared Radiances at the Global Modeling and Assimilation Office

Will McCarty

Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, MD, USA, will.mccarty@nasa.gov

This effort is built upon expanding the handling of infrared measurements within the Gridpoint Statistical Interpolation (GSI) data assimilation system to include measurements affected by clouds. The GSI is the atmospheric assimilation component of The Goddard Earth Observing System Model, Version 5 (GEOS-5) system of models. Infrared measurements that are sensitive to clouds are screened out via quality control. These methods can discard ~85% of infrared channels within the window region. It is desirable to further incorporate these observations into the assimilation system, but there are difficulties including, but not limited to, the nonlinear nature of clouds on the observations, the difficulty of detecting multilayer clouds within a single field-of-view, spectral variations in cloud emissivity, and the separation of atmospheric and cloud signatures.

This effort is currently focused on the incorporation of a graybody assumption into the observation operator and allowing the cloud top pressure to vary in the minimization as part of the control vector, similar to the approach presented in McNally (2009) [1]. This study presents a system that adds the adjusted observation operator and Jacobians, via the Community Radiative Transfer Model (CRTM) and variational cloud top pressure to the GSI. Furthermore, initial results beyond the McNally (2009) methodology will be included, including expanding towards observations affected by thin cirrus.

References

COAMPS-TC- and WRF-EnKF performance comparison assimilating inner core airborne Doppler radar observations

Christopher Melhauser\textsuperscript{a} and Fuqing Zhang\textsuperscript{a}

\textsuperscript{a}Department of Meteorology, The Pennsylvania State University, USA, fzhang@psu.edu

Data assimilation using a Weather Research and Forecasting model (WRF)-based ensemble Kalman filter (EnKF) of P-3 tail-mounted Doppler radial velocities from the inner core of tropical cyclones has been shown to successfully represent the dynamic and thermodynamic structure of the tropical cyclone inner core vortex [1,2]. WRF forecasts initialized from the EnKF analysis exhibited improved track forecasts at lead times beyond 12 h for Hurricane Katrina (2005) and improved intensity forecasts at lead times of 24 to 120 h for 61 tropical cyclones from 2008 to 2010 compared with the National Hurricane Centers operational dynamical models [1,3]. The High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP), a conically scanning Doppler radar mounted on the NASA Global Hawk has shown the potential for tropical cyclone prediction using an observation system simulation experiment (OSSE) [4].

Using an adapted version of the WRF-EnKF system for the Navy’s Coupled Ocean-Atmosphere Mesoscale Prediction System for tropical cyclones (COAMPS-TC), the performance of the WRF-EnKF and COAMPS-TC-EnKF systems are compared for the assimilation of P-3 Doppler radial velocity and Global Hawk HIWRAP super observations (SOs) from the inner core of Hurricane Karl (2010). Dropsonde observations from the Pre-Depression Investigation of Cloud-systems in the Tropics (PREDICT) and NASA’s Genesis and Rapid Intensification Processes (GRIP) field campaigns are used for verification.

References


The wealth of observations acquired by satellite-borne instruments is such that they provide the great majority of all data that are currently assimilated at operational meteorological centres. Whilst satellite data has a large and important impact on forecast skill there are still many observations not being used to constrain the model's forecast, owing to the difficulty of modelling every aspect (e.g. clouds, surface reflection) with sufficient accuracy. Particularly challenging is to simulate observations affected by water in its different phases, as the simulations critically depend on processes that are not always explicitly represented by the numerical weather prediction model (e.g., convection) or by the radiative transfer model (e.g., scattering). Recent studies [1] [2] concerning the assimilation of remote sounding observations in the infrared when clouds are present in the instrument’s field of view, confirm the findings of earlier investigations (e.g., [3] [4]) and show that the assimilation of a subset of the sounding channels assimilated in clear-sky conditions can reduce the mean analysis errors of the atmospheric temperature and water vapour profiles. There is also evidence of error reduction on cloud condensate variables [5].

These results provide a motivation to carry out a detailed investigation of the informative potential of high-spectral resolution infrared sounders in the presence of cloud and to assess possible implications on channel selection strategy. In this talk we will discuss the results of our work on quantification of the information content of all 8461 channels of the Infrared Atmospheric Sounding Interferometer (IASI) using the "scattering parametrisation" configuration in RTTOV to account for cloud radiative effects. A case study during summer 2012 was considered and 11 “ensemble of data assimilations” (EDA) ECMWF forecast members over 137 model levels provided the short-range forecast ensemble used to simulate the emerging radiation from the atmosphere in all IASI channels over the whole globe. First, the information content in observation space was calculated, paying particular attention to the choice of the observation error covariance matrix as well as pre-screening strategies. Then, the analysis error reduction potential of the IASI radiance observations was evaluated both along the dry and the cloud-related components of the state vector using either the forecast ensemble or a full-rank “climatological” error covariance matrix. Finally, implications of our work on the operational 4DVAR assimilation of infrared sounders at ECMWF will be discussed.

References
Evaluating space-based and in-situ observations of tropospheric humidity

Isaac Moradi\textsuperscript{a}, Ralph Ferraro\textsuperscript{b}, and Philip Arkin\textsuperscript{a}

\textsuperscript{a}Earth System Science Interdisciplinary Center (ESSIC), University of Maryland, College Park, MD 20740, \textsuperscript{b}NOAA/NESDIS/STAR, College Park, MD 20740.

Space-based microwave satellite observations measured at the frequencies close to the water vapor absorption line at 183 GHz as well as global operational radiosonde data are the main sources of tropospheric humidity in data assimilation systems. Radiosonde data are available for a long-period and have a high vertical resolution compared to the microwave satellite data. On the other hand, satellite data provide global coverage, but radiosonde stations are very sparse. Both space-based and radiosonde observations are prone to different errors. Radiosonde data are affected by several factors including sensor contamination, daytime radiation bias, sensor icing in mid-upper troposphere, and discontinuity in the data because of the difference between observations from different sonde sensors. Microwave satellite data are also prone to several errors including calibration drift, geolocation error, sensor degradation, and inter-satellite biases.

We present the results of evaluating observations from microwave instruments aboard recently launched the Suomi National Polar-orbiting Partnership (NPP, ATMS instrument) and Megha-Tropiques (SAPHIR and MADRAS instruments) satellites. The study includes inter-comparison and inter-calibration of observations of similar channels from the two satellites, evaluation of the satellite data using high-quality radiosonde data from Atmospheric Radiation Measurement Program, as well as geolocation error correction.

In addition, we present the results of a comprehensive study on quantifying different biases in the current operational radiosonde databases. The study investigates different biases in operational radiosonde data in different layers of the troposphere, i.e., lower-, middle-, and upper-troposphere. The study indicates very large discrepancy between current operational radiosonde sensors that cause large temporal and spatial discontinuity in the current radiosonde archives. The results show that current radiosonde data have very large biases throughout the troposphere especially in mid-upper troposphere, so that the data need to be corrected before being assimilated into reanalyzes or numerical weather prediction models.
An Examination of a Multi-Scale Three-Dimensional Variational Data Assimilation Scheme (MS-3DVAR) in the Kuroshio Extension with Simulated and Real Observations

Philip A. Muscarella\textsuperscript{a}, Matthew Carrier\textsuperscript{b}, and Hans E. Ngodock\textsuperscript{b}

\textsuperscript{a}ASEE Post doc, Naval Research Lab, Stennis Space Center, USA, philip.muscarella.ctr@nrlssc.navy.mil, \textsuperscript{b}Naval Research Lab, Stennis Space Center, USA

A MS-3DVAR method for use with the Naval Coastal Ocean Model (NCOM) is being examined in the region of the Kurshio extension. The advantage of a multi-scale approach to data assimilation is the ability to resolve the multiple spatial scales present in regional ocean models. This method relies on the specification of large and small horizontal correlation length scales and their associated background error variances. Using empirical orthogonal functions (EOF) the variances associated with pre-specified length scales can be determined. An additional benefit of the MS-3DVAR technique is the ability to assimilate coarse and dense collections of observations. The forecast errors for the MS-3DVAR scheme are lower than for a traditional 3DVAR system with similar scales. This is shown using simulated and real ocean observations.
Using Regional-scale OSSEs to Explore the Impact of Water Vapor Sensitive Infrared Brightness Temperatures on Analysis and Forecast Accuracy

Jason A. Otkin and Rebecca Cintineo

aCooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, jasono@ssec.wisc.edu
bCooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison

Regional-scale Observing System Simulation Experiments (OSSEs) of a high impact weather event across the central U.S. are used to examine the impact of water vapor sensitive infrared brightness temperatures on the analysis and forecast accuracy. Compared to a control case without satellite assimilation, wind and temperature analyses were more accurate at the end of the assimilation period when observations sensitive to water vapor in the upper troposphere were assimilated; however, cloud and moisture analyses were most improved when observations sensitive to water vapor in the lower and middle troposphere were assimilated. The more accurate analyses at the end of the assimilation experiments led to improved short-range precipitation forecasts compared to the control case. Equitable threat scores were consistently higher for all precipitation thresholds. These results demonstrate that the ability of water vapor sensitive infrared brightness temperatures to improve not only the 3D moisture distribution, but also the temperature, cloud, and wind fields, enhances their utility within data assimilation systems.
Model reduced 4D-Var method [1] is investigated in the 2D North Sea physical-ecological model (BLOOM/GEM) [2]. Ecological models are characterized by strong nonlinearities and difficulties with their differentiability. For such systems the implementation of the adjoint of the tangent linear approximation of the original model is commonly a challenge. The model reduced 4D-Var method is designed in such a way that the adjoint for the original model is not required. Instead, it is approximated by the adjoint of the tangent linear approximation of the reduced model. Moreover, the technique tackles the initial condition in the reduced space, where it is estimated as a linear combination of principal components of the original model dynamics [3]. Adapting this approach results in a decrease of the model state size by a couple of orders of magnitude, maintaining a relatively good accuracy.

Followed by sensitivity analysis supported by experts opinion, a number of parameters was selected as the most significant in the BLOOM/GEM model [4]. The method was first carried out in a twin experiment framework, where the parameters were calibrated in a combination with the initial condition estimation. Parameter relative error was successfully decreased down to 10%-20% (with respect to the prior error). Moreover, the initial condition size was reduced from 108750 down to 40. Despite this drastic reduction of the control vector size, the method maintained a relatively good accuracy of the initial condition estimates obtaining 75%-90% of the relative error. Additionally, the resulting chlorophyll-a prediction reached up to 35% of a total improvement as calculated for a two year period. Furthermore, the model reduced 4D-Var method was used to calibrate the 2D North Sea BLOOM/GEM model using the chlorophyll-a measurements derived from remotely sensed MERIS data. The predictions of chlorophyll-a concentration resulting from assimilated model were validated using remotely sensed MERIS measurements from a two years period following the assimilation window. The performance of assimilated model was enhanced with respect to the original model, showing for some control strategies even up to 10% of the overall chlorophyll-a prediction improvement in the validation period.

The study highlights the model reduced approach to be an effective tool for approximating the adjoint model in a reduced space for ecosystem applications. It also shows to be proficient in biological parameter calibration. Moreover, it substantially decreased the size of the model initial condition, sustaining its relatively good estimations.

References
Assimilation of MeghaTropique Saphir Radiance data at NCMRWF

V.S. Prasad, C. Johny and Sanjeev Kumar Singh
National center for Medium Range Weather Forecasting, Ministry of Earth Sciences, India.

India and French launched a joint Satellite mission, called MeghaTropiques (MT) for studying water cycle and energy exchanges in the tropics. MT is a unique satellite revolving around the earth in circular orbit with 20 degree inclination and carrying a six channel radiometer, sounder for Probing vertical profiles of Humidity (SAPHIR) in 183 Ghz frequency along with three other sensors. The data from this sensor is recently made available to users.

A Global Data Assimilation and Forecasting (GDAF) system in T574L64 resolution is regularly run in near real time mode at NCMRWF. The analysis of this system is based on Global Statistical Interpolation (GSI) scheme. Necessary changes are made in the GSI to assimilate SAPHIR radiances.

An Observational System Experiment (OSE) to study the impact of SAPHIR radiances is carried out involving this modified GSI. The study period covers a severe cyclone system, Neelam that formed in the Bay of Bengal and crossed south Indian coast on 31 October 2012. The results of this experiment will be discussed in this paper.
Ensemble Kalman filter assimilation of near-surface observations over complex terrain: comparison with 3DVAR for short-range forecasts

Zhaoxia Pu\textsuperscript{a}, Hailing Zhang\textsuperscript{a}, and Jeffrey Anderson\textsuperscript{b}

\textsuperscript{a}Department of Atmospheric Sciences, University of Utah, USA, Zhaoxia.Pu@utah.edu.  
\textsuperscript{b}National Center for Atmospheric Research

Surface observations are the main conventional observations for weather forecasts. However, in modern numerical weather prediction, the use of surface observations, especially those data over complex terrain, remains a unique challenge. There are fundamental difficulties in assimilating surface observations with three-dimensional variational data assimilation (3DVAR). In the first part of this study, a series of observing system simulation experiments is performed with the ensemble Kalman filter (EnKF), an advanced data assimilation method to compare its ability to assimilate surface observations with 3DVAR. Using the advanced research version of the Weather Research and Forecasting (WRF) model, results from the assimilation of observations at a single observation station demonstrate that the EnKF can overcome some fundamental limitations that 3DVAR has in assimilating surface observations over complex terrain. Specifically, through its flow-dependent background error term, the EnKF produces more realistic analysis increments over complex terrain in general. More comprehensive comparisons are conducted in a short-range weather forecast using a synoptic case with two severe weather systems: a frontal system over complex terrain in the western US and a low-level jet system over the Great Plains. The EnKF is better than 3DVAR for the analysis and forecast of the low-level jet system over flat terrain. However, over complex terrain, the EnKF clearly performs better than 3DVAR, because it is more capable of handling surface data in the presence of terrain misrepresentation. In addition, results also suggest that caution is needed when dealing with errors due to model terrain representation. Data rejection may cause degraded forecasts because data are sparse over complex terrain. Owing to the use of limited ensemble sizes, the EnKF analysis is sensitive to the choice of horizontal and vertical localization scales.

Then, we further examine the impact of EnKF data assimilation on the predictability of atmospheric conditions over complex terrain with the WRF model and the observations obtained from the recent field experiments of the Mountain Terrain Atmospheric Modeling and Observations (MATERHORN) Program. Results are compared with these from 3DVAR and a hybrid 3DVAR/EnKF.

References
Preparations for Aeolus Doppler Wind Lidar data and the expected NWP Impact

Michael Rennie\textsuperscript{a}, Andras Horanyi\textsuperscript{b}, and Lars Isaksen\textsuperscript{c}

\textsuperscript{a, b, c} Data Assimilation Section, ECMWF, UK, m.rennie@ecmwf.int

With the expected launch date of mid 2015 for ESA’s Earth Explorer space-based Aeolus Doppler wind lidar mission, the NWP community will soon get an important and novel observing system. The Aeolus L2B/C processing software will provide horizontal line-of-sight (HLOS) wind observations suitable for use in numerical weather prediction (NWP), from the near-surface to 30 km with near-global extent. The processing software has been developed by ECMWF and KNMI (with earlier contributions from Météo-France and DLR). ECMWF will run the L2B/C processing operationally during the mission’s three-year lifetime, with the intention of assimilating the winds in the ECMWF analysis. The software is designed to be portable and easy to use. It is freely available, and NWP centers are encouraged to implement it in their own observation processing system.

This presentation will provide an overview of the software and discuss recent changes to accommodate the continuous mode operation of Aeolus, such as a flexible averaging algorithm for the observations. We go on to present the end-to-end testing results from the Aeolus simulator/L1B/L2B processing chain, based on realistic optical properties and atmospheric inputs, using the expected mission launch-time specifications. The verification of these results provides a realistic indication of the quality of Aeolus L2B products, in particular the random and systematic errors of the winds.

The second part of the talk will present studies performed at ECMWF to investigate the expected NWP impact of continuous mode Aeolus wind data. For the impact assessments real, good quality wind observations were used for a number of Observing System Experiments (OSE) and advanced assimilation diagnostics experiments. The denial studies used aircraft and wind profiler observations to investigate the impact of thinning the wind data. In addition the wind observations from radiosondes, aircraft and profilers were used to define single component (HLOS) wind data for various Aeolus related impact studies, where the impact of HLOS data was investigated. Additional experimentation was conducted to investigate the impact of degraded quality observations, representative for the decreased laser pulse energy expected to be used for the first phase of the Aeolus mission.

The NWP impact results confirm that HLOS wind observations are very beneficial. It is shown that wind data is more important than mass (temperature and humidity) data, so new wind observations like Aeolus wind data would be welcome from the global data assimilation and forecast point of view. Particularly, most benefit is expected in the tropics and in the upper troposphere and lower stratosphere. Furthermore it is shown that a slight increase in random observation error does not severely reduce the impact of the Aeolus data. However, even relatively small biases can have very detrimental effect on the impact. All in all the impact studies at ECMWF conclude that Aeolus wind data is expected to provide valuable impact in global numerical weather prediction.
AMVs – how to make better use of them in NWP?

Kirsti Salonen\textsuperscript{a}, and Niels Bormann\textsuperscript{a}

\textsuperscript{a}Satellite section, ECMWF, United Kingdom, kirsti.salonen@ecmwf.int

Atmospheric Motion Vectors (AMVs) are wind observations derived by tracking clouds or water vapour features in consecutive satellite images. It is assumed that the tracked features act as passive tracers of the atmospheric flow. Traditionally AMVs are interpreted as single-level wind observations assigned to a representative pressure level provided by the AMV producers. AMVs are obtained both from geostationary and polar-orbiting satellites, and already for several years they have provided an important source of tropospheric wind information for global and regional data assimilation systems. AMVs have complicated error characteristics due to the nature of the derivation process. Thus, the key question is how we could get the full potential from these observations for numerical weather prediction. In this presentation two aspects, observation errors and observation modelling are discussed.

The two main sources of errors for AMVs are the wind vector tracking and the height assignment of the observations. The latter is considered to be the dominant source of error and its impact is highly situation dependent. It can be very significant in regions where wind shear is strong but on the other hand it is less relevant in areas where there is not much variation in wind speed with height. These error characteristics can be accounted in data assimilation by estimating the tracking error and error in wind due to error in height assignment separately and combining the estimates as a total, situation dependent, observation error for each AMV. This kind of approach has been recently tested in the ECMWF system. Experiments indicate significant positive forecast impact especially at low levels. The use of situation dependent observation errors has also enabled simplifications to the quality control applied for AMVs. As a result slightly more observations are accepted to be used in the model analysis.

Another area for possible improvements is the interpretation of AMVs. Several studies have suggested some benefit from interpreting AMVs as layer averages instead of single-level wind observations. Studies are ongoing to investigate this aspect in the data assimilation context, and the latest results will be discussed in the presentation.
Ensemble Kalman Assimilation of Global-Hawk-based Data from Tropical Cyclones

Jason A. Sippel\textsuperscript{a}, Scott A. Braun\textsuperscript{a}, Fuqing Zhang\textsuperscript{b}, and Yonghui Weng\textsuperscript{b},

\textsuperscript{a}Laboratory for Atmospheres, NASA GSFC, USA jason.sippel@nasa.gov, \textsuperscript{b}Department of Meteorology, The Pennsylvania State University, USA.

This study utilizes an ensemble Kalman filter (EnKF) the impact of assimilating observations taken over and around hurricanes from the NASA Global Hawk unmanned airborne system. The EnKF has recently proven to be an effective tool for initializing hurricane vortices, and the Global Hawk flies above hurricanes and has the benefit of a 25-30-h flight duration, which is two to three times that of conventional aircraft. The long duration of the Global Hawk gives it a much larger range and on-station capabilities than conventional aircraft, making it a desirable addition to other observing platforms. Observations of interest include radial velocity from the High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP), Advanced Vertical Atmospheric Profiling System (AVAPS) dropsondes, and water vapor and temperature profiles from the scanning High-resolution Interferometer Sounder (S-HIS). We will examine the impact of assimilating thinned “super observations” in terms of analysis accuracy and forecast improvement as a result of assimilation. A comparison is made between assimilating simulated and real HIWRAP data.
NCEP operational Hurricane Weather Research and Forecast (HWRF) model is traditionally run with an advanced vortex initialization scheme developed at EMC to represent the storm location, intensity and structure based on the information provided by NHC for each storm at every 6-hr interval. Except for the initial cycle, HWRF runs in cycled mode where the 6-hr forecast vortex from previous cycle is modified/adjusted to match the observed parameters. For cold start, a composite storm is used to represent the initial vortex. Although operational HWRF uses GSI based regional data assimilation system, no inner-core observations were assimilated due to several constraints imposed by the DA system and discontinuous observations. Initial efforts in assimilating conventional and satellite datasets as well as the Tail Doppler Radar (TDR) data from NOAA-P3s near the storm’s core and its environment using conventional 3DVar (GSI) system revealed negative impact on track and intensity forecasts.

The global modeling system at NCEP (GFS) was upgraded in May 2012 with more advanced EnKF/3DVAR hybrid data assimilation system within the GSI framework. This infrastructure enabled the HWRF team to experiment a more economical one-way hybrid approach to assimilate the TDR data within the HWRF modeling system in real-time. Experimental results run in real-time during the 2012 hurricane season have shown significant positive impact on intensity forecasts for the 19 P3 missions flown. Retrospective testing of assimilation of aircraft recon observations for the past five hurricane seasons (2008-2012) indicated much improved intensity forecasts from TDR only data assimilation. Based on these encouraging results, the TDR DA capability is now included into operations for the 2013 hurricane season.

This presentation will discuss the methodology, results from recon data impact experiments, and future efforts to improve the inner core data assimilation procedures in the operational HWRF modeling system.
Uncertainty Quantification in Satellite-based Precipitation Measurements

Yudong Tian

ESSIC, University of Maryland, College Park, Maryland, USA, yudong.tian@nasa.gov

Data assimilation depends on uncertainty quantification. For satellite-based precipitation measurements, uncertainty originates from many error sources, including systematic errors and random errors. This presentation summarizes our efforts to quantify these errors in six different TRMM-era precipitation products (3B42, 3B42RT, CMORPH, PERSIANN, NRL and GSMaP). For systematic errors, we devised an error decomposition scheme to separate errors in precipitation estimates into three independent components, hit biases, missed precipitation and false precipitation [1]. This decomposition scheme reveals more error features and provides a better link to the error sources than conventional analysis, because in the latter these error components tend to cancel one another when aggregated or averaged in space or time..

For the random errors, we calculated the measurement spread from the ensemble of these six quasi-independent products, and thus produced a global map of measurement uncertainties [2]. The map yields a global view of the error characteristics and their regional and seasonal variations. More recently, we have developed a multiplicative error model to predict the uncertainties when ground validation data are not available [3], and have shown that this model is superior to the commonly-used additive error model in describing and predicting the uncertainty in precipitation measurements.

References


Incorporating Correlated Observation Errors in Ensemble Data Assimilation

J. A. Waller, S. L. Dance, A. S. Lawless and N. K. Nichols

*School of Mathematical and Physical Sciences, University of Reading, UK, j.a.waller@reading.ac.uk

Observations used in combination with model predictions for data assimilation can contain information at smaller scales than the model can resolve. Errors of representativity are errors that arise when the observations can resolve scales that the model cannot. Representativity errors when combined with the errors in the observation operator are known as forward model error. Representativity errors have been shown to be correlated and time dependent [1]*, but currently they are not correctly accounted for in assimilation schemes. A better understanding of these errors, and how they could be calculated, would allow them to be incorporated into the observation error statistics to provide more accurate analyses and enable better use of available observations.

In this work we develop a new method for diagnosing and incorporating correlated and time-dependent forward model error in an ensemble data assimilation system. The method combines an ensemble transform Kalman filter with a method proposed in [2] that uses statistical averages of background and analysis innovations to provide an estimate of the observation error covariance matrix. From this estimate of the observation error covariance matrix the uncorrelated instrument error can be subtracted to provide an online estimate of the time dependent forward model error covariance.

To evaluate the performance of the method we run identical twin experiments in a simplified model. Using this approach we are able to recover the true observation error covariance in cases where the initial estimate of the error covariance is incorrect, and follow time-varying observation error covariances where the length-scale of the true covariance is changing slowly in time. We find also that including the estimated forward model error in the assimilation improves the analysis [3].

*This previous work is the subject of another abstract (Nichols et. al.) submitted to this symposium.

References


Assimilation of Airborne Doppler Radar observations using the GSI-based hybrid ensemble-variational data assimilation system to improve high resolution hurricane forecast by HWRF

Yongzuo Li, Xuguang Wang, Xu Lu, Mingjing Tong, Ming Xue

School of Meteorology, University of Oklahoma, USA
Environmental Modeling Center, NCEP, USA

Corresponding author address: xuguang.wang@ou.edu

A hybrid ensemble-variational data assimilation system has been developed based on the US NCEP operational data assimilation system, GSI. The hybrid data assimilation (DA) system became operational for the US Global Forecast System (GFS) since May 22, 2012. The new hybrid DA system has significantly improved many aspects of the operational global forecasts. Since then, efforts have been made to further develop and test the same hybrid system with the operational Hurricane Weather Research and Forecast (HWRF) modeling system. In this talk, recent progress and results to test the hybrid DA for HWRF to improve the high-resolution tropical cyclone prediction will be presented.

The HWRF hybrid DA system was tested for the prediction of Hurricane Irene (2011) and Sandy (2012), assimilating the airborne Doppler radar data from NOAA hurricane hunters. The model was run with 9km grid spacing. The ensemble at the beginning of the DA cycling and the lateral boundary condition ensemble were provided for the GFS ensemble. Data assimilation cycling experiments were conducted by assimilating one leg of the TDR data per cycle. Verification against independent in situ and remotely sensed observations shows that the analyses provided by the hybrid DA system captures the hurricane structure much better than the GSI 3DVar. Forecast initialized from the analysis of the hybrid system produces substantially smaller track and intensity errors than those such as the operational HWRF forecast, forecasts without assimilating the airborne Doppler radar data and forecasts initialized by the analyses generated by the GSI 3DVAR.

The HWRF hybrid DA system was also further developed so that the hybrid DA can be done at dual resolution with nested domains where the control analysis was at 3km and the ensembles ingested were at 9km. The 3km domain was vortex following during the forecast step of the DA cycle and the free forecast. Initial results show that the nested domain DA capability worked properly. IRENE predicted by the nested domain DA and forecast was stronger than the best track. More results of testing the 3km/9km dual resolution, nested domain DA will also be presented at the symposium.
Optimization of the operational assimilation of radar data at convective scale in AROME France and international cooperations

Eric WATTRELOT\textsuperscript{a}, Thibaut MONTMERLE\textsuperscript{b}, Carlos Geijo GUERRERO\textsuperscript{c}

\textsuperscript{a}CNRM/GAME (Météo-France/CNRS), France, eric.wattrelot@meteo.fr, \textsuperscript{b}CNRM/GAME (Météo-France/CNRS), France, \textsuperscript{c}AEMET, Spain

Radial velocities and reflectivities observed by 24 radars of the French ARAMIS network are currently assimilated operationally in the AROME-France NWP system at convective scale. When precipitating events occur over France, such data play nowadays a significant role in this system by reducing the forecast error variances and by improving forecast scores, especially for precipitations.

The main components allowing the assimilation of such data will be presented and the impact on analysis and forecast will be illustrated on case studies, a posteriori diagnostics and scores.

The optimization of their use in the 3DVar is currently being considered in order to increase the data density, to improve the specification of observation error statistics and to reduce forecast errors. This work is based on a posteriori diagnostics on observation error correlations and the use of specific background error covariances in precipitating areas.

Finally, status of European cooperations involving the ALADIN and the HIRLAM consortia will also be given. As it will be shown, such cooperations have permit to take into account six Spanish radars in AROME within the framework of the HyMeX experiment over the Western Mediterranean.
Accounting for Correlated Observation Errors in the Assimilation of High Resolution Sounders

Peter Weston*, William Bell*, and John Eyre*

*Met Office, United Kingdom. peter.weston@metoffice.gov.uk

Since January 2013 data from IASI are used with a full observation error covariance matrix ($R$) within the Met Office 4D-Var assimilation scheme, accounting for correlations between channels. This has been shown to lead to improved use of the water vapour sensitive channels and an associated improvement in forecast accuracy [1]. The correlated observation errors were estimated using a diagnostic technique described Desroziers [2].

The current scheme only accounts for correlated errors for IASI but an extension to include treatment of inter-channel correlations from other high resolution IR sounders such as AIRS and CrIS will be presented.

Accounting for the correlations leads to different weights being given to observations depending on the relationship of the most correlated channels’ first guess departures. Several case studies in a 1D-Var assimilation scheme will be shown to explain this behaviour.

The main source of error which contributes to the inter-channel error correlations is representativeness error, which results from a scale mismatch between the observations and the model background. It is difficult to isolate and accurately quantify this source of error but there are techniques which can be used to estimate it. Results from running the 4D-Var assimilation at different resolutions and scale matching will be shown.

References
An Evaluation of the NSSL Mesoscale Ensemble

Dustan Wheatley\textsuperscript{a,b}, Kent Knopfmeier\textsuperscript{a,b}, Gerry Creager\textsuperscript{a,b}, Michael Coniglio\textsuperscript{b}, Adam Clark\textsuperscript{a,b}, James Correia\textsuperscript{a,c}, David Dowell\textsuperscript{d}

\textsuperscript{a}Cooperative Institute for Mesoscale Meteorological Studies, Univ. of Oklahoma, Norman, Oklahoma, USA
\textsuperscript{b}NOAA/National Severe Storms Laboratory, Norman, Oklahoma, USA
\textsuperscript{c}NOAA/Storm Prediction Center, Norman, Oklahoma, USA
\textsuperscript{d}NOAA/Earth Systems Research Laboratory, Boulder, Colorado, USA

One task of the NOAA Warn-on-Forecast program is the development of realistic mesoscale backgrounds for downscaling to high-resolution (of order 1 km or less) radar data assimilation experiments. Toward this end, the NSSL Mesoscale Ensemble (NME) has been developed using the Weather Research and Forecasting (WRF) model. A variety of quasi-realtime model output from the NME will be examined during this year’s NOAA HWT Spring Forecast Experiment, to better understand the impact of conventional observations on mesoscale analyses and forecasts of severe weather events.

The NME will be run daily for period 06 May – 07 June 2013 to produce three-dimensional analyses over a CONUS domain with a horizontal grid spacing of 18 km. The 36-member ensemble is constructed from initial and boundary conditions provided by the Earth System Research Laboratory-Rapid Refresh (RAP-ESRL, i.e., RAPv2) forecast cycle starting 1200 UTC. Initial condition perturbations are used to account for uncertainties in the RAP-ESRL analysis, and the WRF physics options are also varied amongst the ensemble members to address deficiencies in model physics. Routinely available observations of altimeter setting, temperature, dewpoint, and horizontal wind components from land and marine surface stations, rawinsondes, and aircraft—as well as satellite winds—are assimilated using an ensemble Kalman filter (DART software) at hourly intervals from 1300 UTC to 0300 UTC the following day. Mesoscale ensemble forecasts are also launched from the 1400, 1600 and 1800 UTC mesoscale analyses, and all terminate at 0300 UTC the next day.

Experiences with examining and evaluating the environmental characteristics of the NME output will be presented. This will include a comparison of 1-h ensemble-mean forecasts to 1-h RAP-ESRL forecasts, the latter of which serve as a first guess to the Storm Prediction Center’s comprehensive surface objective analysis scheme (SFCOA). In addition, a daily realtime WRF run (with 4-km grid) initialized from the 0000 UTC NME analysis is being run in parallel to the established NSSL realtime WRF, which is a “cold start” from the North American Mesoscale model. Guidance from this work will also be shown.
Towards Understanding the Contributions of Satellite-Derived Atmospheric Motion Vectors to the Mesoscale Tropical Cyclone Analyses and Forecasts

Ting-Chi Wu\textsuperscript{a}, Chris Velden\textsuperscript{b}, Sharan Majumdar\textsuperscript{a}, Hui Liu\textsuperscript{c}, and Jeff Anderson\textsuperscript{c}

\textsuperscript{a} Rosenstiel School of Marine and Atmospheric Science, University of Miami, USA, twu@rsmas.miami.edu, \textsuperscript{b} Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, USA, \textsuperscript{c} National Center for Atmospheric Research, USA.

Atmospheric Motion Vectors (AMVs) are derived using a sequence of three satellite images to track targets (including cirrus cloud edges, gradients in water vapor, and small cumulus clouds) every 30 minutes in operation, and are assimilated 3-6 hourly in global forecast models. The enhanced AMVs are specially processed at high resolution by CIMSS in 1-h interval for the duration of Typhoon Sinlaku (2008) and Hurricane Ike (2008). Given that the assimilation of these enhanced AMVs has shown promising mesoscale analyses of track, intensity and structure of the tropical cyclone (Wu et al. 2013), further investigation on understanding where the TC analyses benefit the most from the enhanced AMVs information is motivated.

Several data-denial cycles are prepared, in which AMVs at specified height levels and cut-off distances from the TC center are withheld. These subsets of AMVs are assimilated into the Weather Research and Forecasting (WRF) model with a resolution of 27 km on the analysis grid (and 9 km in the forward forecast model) using the Ensemble Kalman Filter (EnKF) with 84 members. To identify the relative contributions of the different layers of AMVs to the analyses and forecasts of the TC and its environment, three data-denial cycles are designed: eliminate AMVs between 150-350 mb; eliminate AMVs between 350-700 mb; and eliminate AMVs between 700-999 mb respectively. Two further data-denial cycles are prepared, with AMVs withheld within (outside) 10 degrees from the TC center, in order to investigate the contribution of AMVs on the TC structure. Initial results suggest that the interior AMVs and low-level (700-999 mb) AMVs are crucial at maintaining TC intensity and size, and upper-level AMVs are necessary in reducing track errors.

References

An Application Study on Near Surface Channels of Hyper-spectral Infrared Sounder

ZHANG Hua¹, JIN Dazhi², LI Gang²

¹ Numerical Weather Prediction Center, CMA, China, zhangh@cma.gov.cn, ²College of Mathematics & Physics, Nanjing University of Information Science & Technology, China

Abstract: For the Complexity of land surface, satellite radiation data near surface hasn't been full developed and used. Surface temperature is one of the most serious problems, which come from the inaccurately forecast model. This paper is tried to use one dimensional variational (1DVar) method with the infrared hyper-spectral AIRS observations to adjust the surface temperature. Firstly, a series of simulated experiments were conducted to test the capacity of the method of adjusting the surface temperature. The surface temperature is still able to be adjusted effectively even those errors are included for the surface emissivity, temperature profile, the humidity profile and satellite observations. Then, real cases were tested by 1Dvar. The difference of simulation brightness temperature and the observation brightness temperature of lower channels were decreased as the surface temperature was adjusted. Finally, A Global three dimensional variational assimilation model GRAPES-3Dvar were used to do the 10 day cycle assimilation experiment. The results show that the adjusted temperature improves effectively the analytic fields. The height fields of the lower atmosphere, the middle atmosphere and the upper atmosphere are improved. The humidity fields and the wind fields are also obviously improved in the lower atmosphere.

Keywords: Variational Assimilation, Surface Temperature, Surface Emissivity, GRAPES-3Dvar
Precipitation-related radiance bias correction and how GPM can help

Sara Q. Zhang¹, Philippe Chambon², William S. Olson¹, Milija Zupanski³, Arthur Y. Hou¹

¹Mesoscale Atmospheric Process Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, USA
²CNRM-GAME, Météo-France and CNRS, Toulouse, France
³CIRA, Colorado State University, Fort Collins, CO, USA

In the context of data assimilation for numerical weather prediction (NWP), bias between observed and model-simulated radiances represents a combination of instrument measurement bias, systematic errors in observation operators, and forecast errors projected into observation space. Precipitation-sensitive microwave radiances are susceptible to approximations and assumptions on physical properties of precipitation in radiative transfer calculations and model cloud physics schemes. To utilize precipitation-sensitive radiances optimally in NWP systems, we need a bias correction with predictors that are related to precipitation processes, and an independent data reference to constrain the estimation of bias model parameters.

The core observatory of upcoming Global Precipitation Measurements mission (GPM) will provide simultaneous measurements by the GPM microwave imager (GMI) and the dual-frequency precipitation radar (DPR). The observations from DPR contain additional information about the precipitating particle size distribution (PSD) that is critical in detecting systematic errors in radiance observation operators under precipitation conditions. In this work, we first conduct statistical studies on systematic errors of first guess departures of precipitation-sensitive microwave radiances in the Goddard cloud-resolving WRF ensemble data assimilation system (WRF-EDAS) with a symmetric sampling approach. Second, we choose predictors that are precipitation-related, such as hydrometeors in different phases with distinct scattering properties and parameters concerning surface emissivity. Third, we formulate an adaptive algorithm to estimate bias model parameters for selected channels of microwave radiances utilizing coincidental observations from DPR as a constraint. Experiments are carried out by WRF-EDAS using synthetic GMI and DPR data to examine the potential impact of the bias correction to the assimilation of precipitation-sensitive microwave radiances over land.
Enhanced Radiance Bias Correction in the NCEP's Gridpoint Statistical Interpolation Data Assimilation System

Yanqiu Zhu\textsuperscript{ab}, John Derber\textsuperscript{a}, Andrew Collard\textsuperscript{ab}, Dick Dee\textsuperscript{c}, Russ Treadon\textsuperscript{a}, David Groff\textsuperscript{ab}, Paul Vandelst\textsuperscript{ab}

\textsuperscript{a}NOAA National Centers for Environmental Prediction, \textsuperscript{b}I. M. Systems Group, Inc., USA, \texttt{Yanqiu.Zhu@noaa.gov}, \textsuperscript{c}European Centre for Medium-Range Weather Forecasts, UK

The enhancements to the operational radiance bias correction in the NCEP's Gridpoint Statistical Interpolation (GSI) Data Assimilation System have been developed and tested on the development versions of the parallel Global Forecast System (GFS). Enhancement efforts have focused on several aspects of radiance bias correction. First, a modified preconditioning is applied to the bias correction coefficients and the analysis variables to speed up the convergence of the minimization process. Second, the capabilities of detecting any new/missing/recovery radiance data and initializing the bias correction for new radiance data are implemented. The background error variances for the bias correction coefficients are automatically adjusted using an approximation of the analysis error variances from the previous cycle, and the pre-specified predictor parameters are removed. Third, the capability to perform bias correction for passive channels within the GSI is developed. Finally, another major endeavor is that the two-step bias correction procedure currently used is replaced with a one-step variational bias correction scheme within the GSI. The scan angle and the air-mass bias corrections are now obtained consistently along with other analysis variables inside the GSI in the one-step procedure, and it is expected that they could respond quickly to any changes in data quality or algorithm accordingly.

Although experiments conducted with the latest GSI-based hybrid ensemble-variational system show that the one-step enhanced scheme of radiance bias correction is working properly, further tuning over a longer time period may be necessary, and there is still room to improve. One of the issues we will discuss is the larger land/sea difference as the new Community Radiative Transfer Model (CRTM) development improves the microwave sea surface emissivity model. An emissivity sensitivity predictor term is constructed to account for the land/sea difference. Preliminary results are promising, and more experiment results will be shown at the conference.
Impact of ATMS Radiance Data Assimilation on Hurricane Track and Intensity Forecasts Using HWRF

Xiaolei Zou\textsuperscript{a}, Fuzhong Weng\textsuperscript{b}, Banglin Zhang\textsuperscript{c,d}, Lin Lin\textsuperscript{c,d} and Zhengkun Qin\textsuperscript{a}

\textsuperscript{a} Department of Earth, Ocean and Atmospheric Sciences, Florida State University, USA, \texttt{xzou@fsu.edu}, \textsuperscript{b} National Environmental Satellite, Data & Information Service, National Oceanic and Atmospheric Administration, USA, \textsuperscript{c} Earth Resources Technology, Inc., USA, \textsuperscript{d} Joint Center for Satellite Data Assimilation, USA

The Advanced Technology Microwave Sounder (ATMS) onboard the Suomi National Polar-orbiting Partnership (NPP) satellite provides atmospheric temperature- and water vapor-sensitive multi-channel radiance data to support a continuing advance in numerical weather prediction (NWP) for hurricanes and other weather events. The benefits of assimilating ATMS radiances along with conventional and other satellite data streams for improved hurricane forecasts are examined for four landfall hurricane cases that occurred in 2012 Atlantic Ocean. The Hurricane Weather Research and Forecasting (HWRF) system, which employs the National Centers for Environmental Prediction (NCEP) Gridpoint Statistical Interpolation (GSI) data assimilation system, is used. Firstly, two modifications are made to the HWRF modeling system. The first modification is on the HWRF model top, which is raised to ~0.5 hPa. The second modification concerns the cold start embedded in the HWRF system, which is changed to a warm start for the cycling of data assimilation cycle. Secondly, the ATMS data quality control procedure and bias correction methods employed in the GSI system are carefully documented. Thirdly, two pairs of hurricane data assimilation/forecasting experiments are carried out to demonstrate the potential impacts of ATMS radiance data assimilation on hurricane track and intensity forecasts. It is found that the ATMS radiance data assimilation adds significant values to improved hurricane track and intensity forecasts when compared with the parallel runs without ATMS data.
Towards the Assimilation of Near-Surface Winds from Tall Anemometric Wind Farm Towers

Joël Bédard\textsuperscript{a}, Stéphane Laroche\textsuperscript{b}, and Pierre Gauthier\textsuperscript{c}

\textsuperscript{a}Department of Earth and Atmospheric Sciences, UQAM, Canada, bedard.joel@gmail.com, \\
\textsuperscript{b}Data Assimilation and Satellite Meteorology Section, Environment Canada, Canada, \\
\textsuperscript{c}Department of Earth and Atmospheric Sciences, UQAM, Canada.

Hourly wind power prediction plays a key role in the integration of wind power in an energy production network comprising different energy sources. The ability to predict hourly wind power up to 48h lead time relies on accurate Numerical Weather Predictions (NWP) of near-surface winds. Although increasing the resolution of NWP model helps to improve the forecast skill in the lower troposphere, the main sources of forecast errors are still the analysis inaccuracy due to the limited number of near-surface wind observations assimilated, the atmospheric boundary layer modeling, and the growth of large-scale phase and amplitude errors in the analyses.

The main objective of this project is to improve lower tropospheric analyses by assimilating near-surface wind observations from 80m anemometric wind farm towers, as well as 10m wind observations from operational surface stations in the hybrid ensemble variational data assimilation system (EnVar) developed at Environment Canada. To achieve this, it is necessary to complete: 1) an evaluation of near-surface flow correlation with the upper air atmosphere; 2) the estimation of the background error covariances prescribed for use in the assimilation system; 3) the development of an observation operator including a statistical representativeness error correction; and 4) a validation of the method where observation system experiments are performed using near-surface wind observations and verified against non-assimilated collocated radiosondes to assess if the vertical corrections concur with observations.

The background error statistics used in EnVar comprises a stationary homogenous component, as in a 3D-Var, and a flow dependent component from the Ensemble Kalman Filter (EnKF). Preliminary results show that the vertical structures of variances from the stationary homogenous and EnKF components are quite similar, except near the surface where the EnKF background error statistics underestimate the wind, temperature and surface pressure variances. This can be attributed to the fact that the surface analyses are currently not perturbed in the EnKF. However, the cross-correlations are more pronounced in the flow-dependent component and thus, its multivariate impact for single near-surface observation is significantly higher in the vertical for all prognostic variables. This investigation also reveals that the vertical structure of error correlations in the EnKF depends on the local atmospheric stability. However, these results are sensitive to the ensemble size. Even when using 192 members, localization is still needed as spurious long-distance error correlations appear in the original covariances due to poor sampling (especially over complex terrain). Nevertheless, the EnKF tends to capture dynamical features (e.g. coherent tilted increments associated with baroclinic structures) and the temporal correlations enable the analysis increments to evolve with the meteorological system.
Data-Denial Experiments for the Improvement of Wind Energy Forecasts with the NCEP North American Mesoscale Modeling and Assimilation System: The WFIP and POWER Projects

Jacob R. Carley\textsuperscript{a}, Geoff DiMego\textsuperscript{b}, James Wilczak\textsuperscript{c}, Eric Rogers\textsuperscript{b}, Steve Levine\textsuperscript{d}, Jeff Whiting\textsuperscript{e}, Yanqiu Zhu\textsuperscript{e}, Laura Bianco\textsuperscript{c,f}, Irina Djalalova\textsuperscript{e,f}, and Yelena Pichugina\textsuperscript{c,f}

\textsuperscript{a}UCAR Visiting Scientist Program, USA, jacob.carley@noaa.gov, \textsuperscript{b}NOAA/NWS/NCEP/EMC, \textsuperscript{c}NOAA/ESRL/PSD, \textsuperscript{d}SRG Inc., \textsuperscript{e}IMSG, \textsuperscript{f}CIRES

In a partnership with the Department of Energy (DOE) and the Earth Systems Research Lab’s Global Systems and Physical Sciences Divisions (ESRL/GSD and ESRL/PSD), the National Centers for Environmental Prediction/Environmental Modeling Center (NCEP/EMC) has participated in two separate projects which focused on improving short-term wind forecasts, $O$(6 hrs), for the wind energy community. The first, the Wind Forecast Improvement Project (WFIP), involved a year-long field experiment which covered two separate study regions over the Northern and Southern Great Plains of the United States. In both regions special wind profiler, SODAR, and RASS observations were taken throughout the duration of the project. Using these special observations, along with industry-provided tall tower and nacelle wind speed observations, data-denial experiments were conducted with the North American Mesoscale model forecast system (NAM) to assess the impact of these special observations on the wind energy forecast over two, week-long periods. In addition to performing analysis/forecast cycles with the standard 12 km NAM domain the system was also extended to include an analysis/forecast cycle for its 4 km CONUS-nest.

The second project, POWER (Position of Offshore Wind Energy Resources), is a collaborative effort with DOE, ESRL/GSD, and ESRL/PSD to provide information about observation networks needed to support offshore wind energy development. Currently, maximizing the potential of offshore wind energy resources is made difficult by our inability to measure the shallow layer above the sea-surface, where offshore wind turbine rotors reside. During the summer 2004 New England Air Quality Study $\sim$13 coastal wind profilers and one shipborne Doppler lidar were deployed in the New England area. The POWER project takes advantage of these pre-existing data and uses them in a set of data-denial experiments with an hourly-updated version of the NAM system. These data-denial experiments evaluate the potential benefits of assimilating coastal profiler observations upon short-term, offshore wind energy forecasts.

Preliminary results from both WFIP and POWER projects will be presented along with future work and plans for the hourly-updated NAM forecast system.
Development of IASI Preprocessing at KIAPS and Preliminary Results

Hyoung-Wook Chun\textsuperscript{a}, Sangil Kim\textsuperscript{b}, Yoonjae Kim\textsuperscript{b}, Jeon-Ho Kang\textsuperscript{a}, Sihye Lee\textsuperscript{a}, and Ju-Hye Kim\textsuperscript{a}

\textsuperscript{a}Data Assimilation Team, Korea Institute of Atmospheric Prediction Systems, Korea, hw.chun@kiaps.org,  
\textsuperscript{b}Numerical Data Application Division, Korea Meteorological Administration, Korea.

The preprocessing system of Infrared Atmospheric Sounding Interferometer (IASI) radiances developed at Korea Institute of Atmospheric Prediction Systems (KIAPS) is introduced and its preliminary results are described here. Brightness temperature (TB) observed for one month in November, 2012 is extracted from IASI Level1D BUFR data using ECMWF BUFR decoder. The background TB is simulated by RTTOV 10.2 using UM 6-hour forecast data.

After gross error checking and simple cloud screening, the bias correction of background departures (i.e. difference between the observed TB and corresponding background TB). The background departure helps us to understand the characteristics of IASI data and bias correction. Small bias is observed for the background departure over the channels for high altitude temperature sounding and water vapor sounding channels. On the other hand, large bias is observed for the background departure for atmospheric window channels. The scatter plots of the observed TB and the background TB show that the large bias for window channels is partly due to cloud contamination. We are currently testing the various cloud screening methods of other organizations and the test results will be presented.

We have also checked the bias of less cloudy contaminated channels via the off-line bias correction method for IASI used in [1]. There are three types of background departure errors (i.e. scan errors, air-mass errors, and random errors). The scan bias is simply computed as the average of the background departure for each viewing angle and each latitude bin. Satellite viewing angles for 120 IASI scan positions are checked and the histograms of the bias are utilized over each latitudinal bin to find a scan bias error pattern. The air-mass bias is then computed by multiple linear regression analysis of scan-bias-corrected background departures and predictors. We are currently testing the various predictors (i.e. thickness of some part of the atmosphere, total precipitable water, surface temperature, etc.) to find the predictors most suitable for the KIAPS preprocessing system.

References

Quantify the MODIS Fractional Snow Cover Retrieval Errors over CONUS and Assimilation Experiments

Jiarui Dong\textsuperscript{a,b}, Mike Ek\textsuperscript{a}, Dorothy Hall\textsuperscript{c}, Christa Peters-Lidard\textsuperscript{d}, Brian Cosgrove\textsuperscript{e}, Jeff Miller\textsuperscript{c}, George Riggs\textsuperscript{c}, Youlong Xia\textsuperscript{a,b}, Weizhong Zheng\textsuperscript{a,b}, Jesse Meng\textsuperscript{a,b}

\textsuperscript{a} NOAA/NCEP/EMC, College Park, Maryland, 20740 (Jiarui.Dong@noaa.gov), \textsuperscript{b} I.M. System Group, Rockville, MD20852, \textsuperscript{c} Cryospheric Sciences Laboratory, NASA/GSFC, Greenbelt, Maryland, 20771, \textsuperscript{d} Hydrological Sciences Laboratory, NASA/GSFC, Greenbelt, Maryland, 20771, \textsuperscript{e} NOAA/NWS/OHD, Silver Spring, Maryland.

As both model predictions and remotely-sensed estimates are characterized by different uncertainties at different times and locations, the most accurate snow pack status estimate results from the assimilation of remotely-sensed estimates into a land surface model, with correct observation and model error specifications. Understanding and quantifying satellite-based remotely sensed snow cover uncertainty are critical for its successful utilization. The Moderate Resolution Imaging Spectroradiometer (MODIS) snow cover errors have been previously recognized to be associated with factors such as cloud contamination, snowpack grain sizes, vegetation cover, and topography, however, the quantitative relationship between the retrieval errors and these factors remains elusive. Joint analysis of the MODIS fractional snow cover (FSC) from Collection-6 (C6) and in-situ air temperature and snow water equivalent (SWE) measurements provides a unique look at the error structure of the MODIS C6 FSC products. Analysis of the MODIS FSC data set over the period from 2000 to 2005 was undertaken over the Continental US (CONUS) with an extensive observational network. When compared to MODIS Collection-5 (C5) snow cover area (SCA), the MODIS C6 product demonstrates a large improvement in detecting the presence of snow cover, especially in the early and late snow seasons. However, significant spatial and temporal variations in accuracy still exist, and a proxy is required to adequately predict the expected errors in MODIS C6 FSC retrievals. We demonstrate a relationship between the MODIS FSC retrieval errors and temperature over the CONUS domain, captured by a cumulative double exponential distribution function. The quantitative nonlinear relationship between MODIS FSC and model air temperature will enable users to more efficiently assimilate MODIS snow cover information into various hydrological applications, and the performance of the error quantitative prediction will be evaluated through assimilation experiments.
Statistical Model for the Forecasting of Spatial Chlorophyll Concentration in the Red Sea

Denis Dreano\textsuperscript{a}, Ibrahim Hoteit\textsuperscript{b}, and Bani Mallick\textsuperscript{c}

\textsuperscript{a} Computer, Electrical and Mathematical Sciences & Engineering Division, King Abdullah University of Science and Technology, Saudi Arabia, \textsuperscript{b} Computer, Electrical and Mathematical Sciences & Engineering Division, King Abdullah University of Science and Technology, Saudi Arabia, ibrahim.hoteit@kaust.edu.sa, \textsuperscript{c} Department of Statistics, Texas A&M university, USA.

The phytoplankton is the basis of the marine food chain, and, as such, plays a key role in the ecosystem and fisheries. Thanks to satellite images we can estimate its concentration in space and time using the chlorophyll level as a proxy. In this work we propose a statistical model for the chlorophyll concentration spatio-temporal process. This model is twofold: A multivariate statistical model for the seasonal means and a physical statistical model for the modelling of the anomalies. We formulate this model in a Bayesian hierarchical modeling framework for inferring its parameters from the data. We also evaluate how the proposed model performs for filtering and forecasting the data compared to descriptive statistical models.
Assimilation of Freeze-Thaw Observations into the NASA Catchment Land Surface Model

Leila Farhadi\(^a\), Rolf Reichle\(^b\), and Gabrielle De Lannoy\(^b\)

\(^a\)Department of Civil and Environmental Engineering, George Washington University, Washington, DC 20052, USA, lfarhadi@gwu.edu, \(^b\)Global Modeling and Assimilation Office, NASA, Goddard Space Flight Center, Code 610.1, Greenbelt, MD 20771, USA

The land surface freeze-thaw (F/T) state controls hydrological and carbon cycling and thus affects water and energy exchanges at land surface. In this research an Observing System Simulation Experiment is conducted using synthetically generated measurements of the F/T state for a region in North America (90°-110°W longitude, 45°-55°N latitude). The synthetic “truth” is generated using the NASA Catchment land surface model forced with surface meteorological fields from the Modern-Era Retrospective Reanalysis for Research and Applications (MERRA). To generate synthetic measurements, the true categorical F/T state is corrupted with a prescribed amount of F/T classification error. The assimilation experiment employs the same Catchment model except that forcing errors (relative to truth) are introduced via the application of meteorological forcing fields from the Global Land Data Assimilation System (GLDAS). A rule-based approach that incorporates model and observational errors is developed and used for assimilating the categorical F/T measurements into the land surface model (F/T analysis). The effect of the F/T analysis on land surface temperature, soil temperature and soil moisture is examined. In a real-world experiment, the synthetic F/T observations are replaced with F/T observations from the Advanced Microwave Scanning Radiometer Enhanced (AMSR-E). The ultimate goal of this project is to provide a framework for the assimilation of SMAP (Soil Moisture Active Passive) F/T observations into the NASA Catchment land surface model.
Assessing the Contribution of Surface Land Observations in CPTEC/INPE
G3DVAR

Maurício Granzotto Mello*, Fábio Luiz Rodrigues Diniz*, Luis Gustavo Gonçalves de Gonçalves*, and
Dirceu Luis Herdies*

* Center for Weather Forecasting and Climate Studies (CPTEC), National Institute for Space Research
(INPE), Brazil, mauricio.mello@cptec.inpe.br

The Center for Weather Forecast and Climate Studies from the Brazilian National Institute for
Space Research (CPTEC/INPE) replaced its former data assimilation system, the Global
Physical-Space Statistical Analysis System (GPSAS) by the Global 3DVar (G3DVAR). The latter
is based on the Gridpoint Statistical Interpolation (GSI) jointly developed by NOAA, NASA and
NCAR, implemented on the Atmospheric Global Circulation Model developed at the
CPTEC/INPE (AGCM/CPTEC/INPE). The new system, operational at CPTEC since January
2013, assimilates a variety of conventional and non-conventional observations every 6 hours.

CPTEC/INPE’s Group on Data Assimilation Developments (GDAD) is improving the system in
an effort to use the observational data sets available at the center, for instance a surface observing
system available from the Brazilian National Institute of Meteorology (INMET). Part of this
observing system is present in the Global Telecommunication System (GTS) and, consequently,
is being ingested operationally in the G3DVAR analysis whereas a substantial number of
observations is yet to be included. This presentation will discuss practical aspects of the inclusion
of this observing system of conventional observations into CPTEC/INPE G3DVAR.
Furthermore, this presentation will show preliminary results using all operational data used by
G3DVAR in the presence of this new observing system.
An Enhanced Methodology for Satellite Data Assimilation in a Mars Atmosphere Reanalysis

Steven J. Greybush\textsuperscript{a}, Ross N. Hoffman\textsuperscript{b}, Thomas Nehrkorn\textsuperscript{b}, Eugenia Kalnay\textsuperscript{a}, Yongjing Zhao\textsuperscript{a}, Matthew J. Hoffman\textsuperscript{c}, and R. John Wilson\textsuperscript{d}

\textsuperscript{a}Department of Atmospheric and Oceanic Science, The University of Maryland, College Park, MD, USA, greybush@atmos.umd.edu, \textsuperscript{b}Atmospheric and Environmental Research, Lexington, MA, USA, \textsuperscript{c}Rochester Institute of Technology, Rochester, NY, USA, \textsuperscript{d}GFDL, Princeton, NJ, USA.

Spacecraft observations of the atmosphere of Mars from the Thermal Emission Spectrometer (TES) and Mars Climate Sounder (MCS) instruments enable detailed studies of Martian weather and climate. Using the Local Ensemble Transform Kalman Filter (LETKF) we have assimilated retrieved temperature profiles into the Mars Global Climate Model (MGCM) to create a multi-annual reanalysis of temperature, winds, and surface pressures.

The retrieval process effectively smoothes a true profile in the vertical, then mixes it with a prior profile. However, Hoffman et al. [1] found sensitivity to the choice of prior profile for Mars TES. Therefore we introduce a methodology (outlined in Hoffman [2] and inspired by Rodgers [3]) that removes the influence of the prior, with the goal of using interactive priors and covariance from the data assimilation system. Here, standard retrievals are converted to observations that have zero mean, uncorrelated, and unit variance expected errors. The new observation operator is simply a weighted average of temperatures at retrieval pressure levels, the weights being functions of inputs and outputs of the retrieval process namely the prior and posterior temperature profile and covariances. The technique also makes use of the EOF representation for data compression, data thinning based on vertical degrees of freedom, vertical localization based on weighting functions, representativeness error, and superobservations. We test this approach on Optimal Spectral Sampling (OSS) TES temperature retrievals in our Mars data assimilation system.

References


Assimilation of Simulated High-Resolution All-Sky Radiance and Radar Data for Storm-Scale Ensemble Forecasts

Youngsun Jung\textsuperscript{a}, Ming Xue\textsuperscript{a,b}, and Lewis Grass\textsuperscript{c}

\textsuperscript{a} Center for Analysis and Prediction of Storms (CAPS), University of Oklahoma (OU), USA, youngsun.jung@ou.edu, \textsuperscript{b} School of Meteorology, University of Oklahoma, USA, \textsuperscript{c} Cooperative Institute for Research in the Atmosphere, Colorado State University, USA.

Most operational numerical weather prediction (NWP) systems assimilate only clear-sky radiance data because of issues with cloudy radiance data, including nonlinearity of the forward observation operator, non-Gaussian observation errors, and non-stationarity of background errors \cite{1}, and because the limited capabilities of the coarse-resolution NWP model in adequately resolving and representing clouds and precipitation. Recent advances in NWP models, including the increase to convection-permitting or convection-resolving resolutions and better and explicit representation of cloud and precipitation processes, together with advancement in radiative transfer modeling in the presence of clouds, and development of ensemble-based data assimilation techniques more capable of handling nonlinear processes and observations, are all promising the potentially more effective utilization of radiance data in all-sky conditions to improve convective-scale weather forecasting.

This study investigates the potential impact of simulated radiance data from the future GOES-R satellite on analysis and forecasting using an ensemble Kalman filter (EnKF) through realistic observing system simulation experiments (OSSE). A nature run is created using the Weather Research and Forecasting (WRF) model running at 4 km grid spacing, using an initial condition that includes radar data. The Community Radiative Transfer Model (CRTM) is used to create the simulated GOES-R radiance data and as the observation operator in the EnKF, while the forecast model used in the OSSE is the Advanced Regional Prediction System (ARPS) running at the same resolution. The radiance data are assimilated with or without simulated WSR-88D radar data.

Preliminary results show that both simulated satellite radiance and simulated radar observations significantly improved the analyses in regions where there are no clouds, primarily by removing spurious clouds. In regions where there are clouds, the impact of satellite data is smaller when assimilated alone but still positive in most microphysical states. Radar data are found to be more effective in estimating precipitating hydrometeors. A more detailed error analysis and the impacts on forecasts will be presented at the symposium.

References

The KIAPS Observation Processing System Development for the Satellite Data Assimilation

Jeon-Ho Kang, Hataek Kwon, Hyoung-Wook Chun, Ju-Hye Kim, and Sihye Lee

Data Assimilation Team, Korea Institute of Atmospheric Prediction Systems (KIAPS), Seoul, Korea, jh.kang@kiaps.org

The Korea Institute of Atmospheric Prediction Systems (KIAPS) was founded in 2011 by the Korea Meteorological Administration (KMA) for a nine-year (2011-2019) project to develop Korea’s own global Numerical Weather Prediction (NWP) system. KIAPS is in the last year of its first development phase (2011-2013).

The KIAPS data assimilation team has been developing the KIAPS Observation Processing System (KOPS) as a part of KIAPS data assimilation system. At this stage, a prototype framework for the satellite radiance data (AMSU-A, IASI), and Global Positioning System Radio Occultation (GPS-RO) data processing system has been developed using the fortran 90/95 code. KOPS adopted the RTTOV v10 (Radiative Transfer for TOVS) for the AMSU-A and IASI radiance, and the ROPP (Radio Occultation Processing Package) for the GPS-RO, to implement observation operator. The observation data obtained from KMA GTS get extracted via the BUFR decoder. The background fields such as temperature, specific humidity, geopotential height and pressure used for the bias correction and quality control of the observation was prepared from the KMA-UM (Unified Model) forecast.

Interpolating the UM forecast fields on a regular latitude-longitude grid into the observation space is rather straightforward, but interpolating unstructured background fields on a cubed-sphere grid into the observation space is not so simple, and additionally computational efficiency should also be considered. Currently, the “index-based point search method” concerning a virtual regular grid (e.g. Plate-Carree) with a relatively high horizontal spatial resolution is under development for the unstructured background fields.
Development of KIAPS Observation Processing System: AMSU-A Bias Correction Modules

Sihye Lee, Ju-Hye Kim, Hyoung-Wook Chun, and Jeon-Ho Kang

Data Assimilation Team, Korea Institute of Atmospheric Prediction Systems (KIAPS), Seoul, Korea, sh.lee@kiaps.org

As a part of the KIAPS Observation Processing System (KOPS), we have developed the modules for satellite radiance data pre-processing and quality control, which include observation operators to interpolate model state variables into observation space radiance. AMSU-A (Advanced Microwave Sounding Unit-A) Level-1D radiance data was extracted using the BUFR (Binary Universal Form for the Representation of meteorological data) decoder and a first guess was calculated with RTTOV10.2. Both softwares were run via the parallel interface, i.e. MPI. For initial quality checks, the pixels contaminated by large amount of cloud liquid water, heavy precipitation, and sea ice were removed. Different channels for assimilation, rejection, or monitoring were selected for different surface types since the errors from the skin temperature were caused by inaccurate surface emissivity. In radiance data pre-processing, correcting the bias caused by the instruments and radiative transfer model errors is crucial. We have developed bias correction modules in two steps, based on 30-day innovation statistics (observed radiance minus background; O-B). The scan bias correction was calculated individually for 10 degree latitude bands. Then a global multiple linear regression of the scan-corrected innovations against several predictors (e.g., 850-300 and 200-50 hPa thicknesses, surface skin temperature, and total column precipitable water [1]) was employed to correct the air-mass bias. Some weighting is applied to the regression for assimilation channel selections for such reason that stratospheric channels are not dependent on the surface skin temperature predictors.

References
Local Ensemble Transform Kalman Filter Assimilation of Precipitation with the NCEP Global Forecasting System

Guo-Yuan Lien\textsuperscript{a}, Eugenia Kalnay\textsuperscript{a}, and Takemasa Miyoshi\textsuperscript{b}

Email: gylien@atmos.umd.edu
\textsuperscript{a}Department of Atmospheric and Oceanic Science, University of Maryland, College Park, Maryland, USA, \textsuperscript{b}RIKEN Advanced Institute for Computational Science, Kobe, Japan.

Precipitation has long been one of the most important meteorological observations. Although many in-situ and satellite based precipitation observations have been made available, the nonlinear observation operator and the non-Gaussianity of the precipitation variable pose difficulties in its assimilation. It is relatively easy to force the model precipitation to be close to the observed values; however, since this is not an efficient way to modify the potential vorticity field that the model would remember, model forecasts tend to lose their additional skill after few forecast hours.

We propose to use a local ensemble transform Kalman filter (LETKF) to assimilate precipitation observations. The ensemble based data assimilation features the flow-dependent background error covariance, which is able to relate the precipitation variable to other “master” dynamical variables based on the original nonlinear moist physical parameterization in the model. In addition, we also propose two changes in the precipitation assimilation process: a) transform precipitation into a variable with a Gaussian distribution used in the assimilation, and b) only assimilate precipitation at the locations where at least some ensemble members have positive precipitation. In observing system simulation experiments (OSSEs) using a simplified but still realistic general circulation model, we have seen promising improvement by precipitation assimilation [1]. The model background based observation selection criterion plays an essential role in improving the analyses, and the Gaussian transformation of precipitation variables is particularly useful in the case of large observation errors. Based on the experience obtained using the OSSEs, we are going to conduct real precipitation assimilation experiments using the National Centers for Environmental Prediction (NCEP) Global Forecasting System (GFS) model. The TRMM Multisatellite Precipitation Analysis (TMPA) will be assimilated into the model with a newly developed GFS-LETKF data assimilation system. Preliminary results will be shown in this presentation.

References
The Use of Doppler Radar Observations at NCEP

Shun Liu, Geoff DiMego, Matthew Pyle, Wan-Shu Wu, Shucai Guan, David Parrish and John Derber

aIMSG/ National Centers of Environmental Prediction, College Park, Maryland, Shun.Liu@noaa.gov.
bNOAA/National Centers of Environmental Prediction, College Park, Maryland

The entire WSR-88D (Weather Surveillance Radar -1988 Doppler) radar network is upgraded with dual-polarization technology recently. The National Centers for Environmental Prediction has developed the capability of real-time accessing and processing radar data with dual-pol variables. Radar data quality control is enhanced by utilizing dual-pol variables to identify meteorological echoes and non-meteorological echoes. The data quality of radar reflectivity and radial wind are improved by more accurately removing non-meteorological echoes.

After quality control, the radial winds from WSR-88D network are directly analyzed by NCEP grid-point statistic interpolation (GSI) analysis system and assimilated in operational NDAS (North American model Data Assimilation System). The cloud analysis package developed by Global Systems Division (GSD) is modified and used to analyze reflectivity with NCEP’s forecast model background. The radar radial winds together with reflectivity are assimilated every three hours in NDAS parallel. The parallel test from Feb, 23 2013 to April, 23 2013 shows the precipitation forecast score is improved. The impact of radial wind and reflectivity on the analysis and forecast will be further examined in spring storm season.
A BUFR and GRIB Tailoring System for NPP/JPSS and GCOM Products

Yi Song\textsuperscript{a}, Thomas King\textsuperscript{a}, and Walter Wolf\textsuperscript{b}

\textsuperscript{a}IMSG at NOAA Center for Satellite Applications and Research, USA, Yi.Song@noaa.gov, 
\textsuperscript{b}NOAA/NESDIS/STAR, USA.

A tailoring software system that will convert the satellite products into Binary Universal Form for the Representation of meteorological data (BUFR) and GRIdded Binary Edition 2 (GRIB2) formatted files is under development at NOAA/NESDIS/STAR. This Reformatting Toolkit will convert the products of the NPOESS Preparatory Project (NPP)/Joint Polar Satellite System (JPSS) and the Global Change Observation Mission 1st - Water (GCOM-W1) Advanced Microwave Scanning Radiometer 2 (AMSR2) into BUFR and GRIB2 files. The current toolkit development schedule consists of four phases, each adding new tailoring capabilities. In phase 1, the NPP Cross-track Infrared Sounder (CrIS) Radiances, Advanced Technology Microwave Sounder (ATMS) Radiances and Visible/Infrared Imager Radiometer Suite (VIIRS) Radiances will be converted into BUFR files. In phase 2, this software system will reformat the NPP VIIRS Aerosol Optical Thickness (AOT), VIIRS Sea Surface Temperature (SST), Ozone Mapping and Profiler Suite (OMPS) Nadir Profile (NP) and OMPS Total Column (TC) data into BUFR files. In phase 3, the NPP VIIRS Polar Winds will be converted into BUFR file and the Green Vegetation Fraction will be converted into GRIB2 file. In phase 4, this software will convert the GCOM-W1 AMSR2 Microwave Brightness Temperature, Total Precipitable Water (TPW), Cloud Liquid Water (CLW), Sea Surface Temperature (SST), Sea Surface Winds (SSW) into BUFR files and Soil Moisture (SM) into GRIB2 file, and convert NPP Ozone Limb Profile into BUFR file. Currently, the toolkit is running in the NPP Data Exploitation (NDE) environment tailoring phase 1 and 2 products. NDE is distributing these tailored products to the NOAA Environmental Modeling Center (EMC) and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) in near real-time. The phase 3 and 4 tailoring capabilities are currently in development with phase 3 update scheduled for delivery to NDE in the summer of 2013. The details of this toolkit design and its products will be discussed.
A Simple Model to Simulate the Assimilation of Vertical Motion from Cloudy Satellite Imagery

Matthew Wakeling\textsuperscript{a}, John Eyre\textsuperscript{a}, Sue Hughes\textsuperscript{b}, and Ian Roulstone\textsuperscript{b}

\textsuperscript{a} Met Office, Fitzroy Road, Exeter, EX1 3PB, UK, matthew.wakeling@metoffice.gov.uk, \\
\textsuperscript{b} University of Surrey, Guildford, GU2 7XH, UK.

Satellite infra-red sounders are invaluable tools for revealing information on the structure of the atmosphere. They provide much of the information used to initialise atmospheric models, especially in regions that do not have extensive ground-based observations, such as oceans. However, in the presence of cloud, much of this information must be discarded, as the cloud layer is opaque to infra-red radiation. This means that in those situations where information is most desired (such as a developing weather system), it is also very limited in coverage.

A study into the feasibility of retrieving vertical atmospheric motion from sequences of infra-red geostationary satellite images has been undertaken. A single-column model of the atmosphere simulates cloud development with vertical motion, allowing the characteristics of a 2D-Var data assimilation system using a single simulated infra-red satellite observation to be studied. The adjoint method is sufficient for producing an accurate gradient for the cost function, but the non-linear nature of cloud formation causes the minimisation to be very poorly conditioned. The conditioning varies very strongly with the atmospheric variables. Minimisation is achieved using preconditioned conjugate gradients.

The model was provided with a background with values for humidity (with error of 10\%) and temperature (with error of 1K). Assimilating simulated infra-red radiances every 15 minutes over an observation window of 6 hours allows vertical motion to be retrieved with an error of half a centimetre per second in some conditions. Moreover, evaluating the Hessian of the cost function at the minimum provides an estimate of the reliability of the retrieval. This allows atmospheric states that do not provide sufficient information for retrieval to be rejected (such as a cloudless atmosphere or a non-moving opaque cloud layer in the upper troposphere). Retrieval is most accurate with a small upwards motion, with error increasing slowly with larger upward motion and increasing rapidly with downwards motion.
Height correction AMVs with airborne lidar observations

Martin Weissmann\textsuperscript{a}, Harald Anlauf\textsuperscript{b}, Alexander Cress\textsuperscript{b}, Kathrin Folger\textsuperscript{c} and Heiner Lange\textsuperscript{c}

\textsuperscript{a}Hans-Ertel-Centre for Weather Research, Data Assimilation Branch, LMU München, Germany, martin.weissmann@lmu.de, \textsuperscript{b}Deutscher Wetterdienst, Offenbach, Germany, \textsuperscript{c}Hans-Ertel-Centre for Weather Research, Data Assimilation Branch, LMU München, Germany

Uncertainties in the height assignment of Atmospheric Motion Vectors (AMVs) are the main contributor to the total AMV wind error and these uncertainties introduce errors that can be horizontally correlated over several hundred kilometers, which poses a severe issue for their assimilation in NWP models. For this reason, we investigate how to improve the height assignment of AMVs, at first with independent airborne lidar observations and by treating AMVs as layer-winds instead of winds at a discrete level. In a second step, AMVs are now corrected with CALIPSO satellite observations based on the results of the airborne study.

The airborne lidar-AMV height correction reveals that the wind error of AMVs can be reduced by 10-15\% when AMV winds are assigned to a 100-150 hPa deep layer beneath the cloud top derived from nearby lidar observations [1]. The correction is performed using airborne lidar observations during the THORPEX Pacific Asian Regional Campaign 2008. In addition to the reduction of AMV errors, the lidar-AMV height correction is expected to reduce the correlation of AMV errors as lidars provide independent information on cloud top heights. First results from the correction of AMV heights with spaceborne lidar observations from CALIPSO indicate that similar improvements can be reached.

Furthermore, AMVs have been compared to dropsonde and radiosonde winds averaged over vertical layers of different depth to investigate the optimal height assignment for AMVs in data assimilation. Consistent with previous studies, it is shown that AMV winds better match sounding winds vertically averaged over ~100 hPa than sounding winds at a discrete level. The comparison to deeper layers further reduces the RMS difference, but introduces systematic differences of wind speeds.

The Impact of the Temporal Spacing of Observations on Analysis Errors

John Eyre*, and Peter Weston*

*Met Office, United Kingdom, peter.weston@metoffice.gov.uk.

This poster presents a theoretical study of the impact of the temporal spacing of observations on average analysis errors in a simple system analogous to a numerical weather prediction data assimilation system. The results are relevant to questions concerning the optimal distribution of polar-orbiting satellites, and particularly to the question of how available satellite assets might be deployed in the three orbital planes recommended by the World Meteorological Organisation in its “Vision for the Global Observing System in 2025”.

The results of this study show that the sensitivity of analysis error to observation spacing depends on the metric used. The mean analysis error variance is sensitive to observation spacing, but the mean analysis “accuracy” (defined here as the inverse of error variance) is not sensitive in the limit of zero model error. Moreover, although the sensitivity of mean analysis error variance is small when forecast error variances double at their average rate (~12 hours), it is much greater when doubling times are shorter (6 or 3 hours), as might be expected in some high-impact weather events. The results support the case for deploying satellites in orbits that are approximately equally spaced where possible.

In initial experiments, it is assumed that observations from satellites deployed in different orbits have equal information content. In subsequent experiments, information content is simulated for a range of systems corresponding to present and future satellite observing systems. In addition to satellites operational in the period 2010-2011, the potential has been assessed of data from the satellites Suomi-NPP, Metop-B and FY-3C, and also from proposed future systems – hyperspectral infra-red sounders on a ring of geostationary satellites, and an enhanced constellation of radio occultation instruments. In each case, the impact of these observations on mean analysis error variance is assessed.
DIRECT ASSIMILATION OF ALL-SKY SEVIRI IR10.8 RADIANCES IN TC CORE AREA USING AN ENSEMBLE-BASED DATA ASSIMILATION METHOD

Man ZHANG\textsuperscript{a}(Man.Zhang@colostate.edu), Milija ZUPANSKI\textsuperscript{a}, and John A. KNAFF\textsuperscript{b}

\textsuperscript{a} Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO, USA, \textsuperscript{b} NESDIS/STAR-Regional and Mesoscale Meteorology Branch, Fort Collins, CO, USA.

In view of the growing interests in the direct assimilation of cloud and precipitation-affected satellite radiances, the effects of hourly updated hybrid variational/ensemble data assimilation system (HVEDAS) with all-sky IR10.8 radiances collected from the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) instrument, is investigated for the developing stage of Hurricane Fred (2009). In this study, the Maximum Likelihood Ensemble Filter (MLEF) developed at Colorado State University is applied to a modified version of the NOAA’s operational Hurricane WRF (HWRF, 2011) system to directly assimilate all-sky satellite observations in TC core area with 9-km horizontal grid spacing. Other NOAA codes include: (i) Gridpoint Statistical Interpolation (GSI) forward model, and (ii) Community Radiative Transfer Model (CRTM).

A data pre-processing procedure is applied to the all-sky IR10.8 to minimize the differences between model and observations. Verification against a control run and independent observations indicates a positive effect of the cloud information assimilated into the model, especially on the amount and distribution of the cloud ice water content. The case studies show that the pattern and location of the forecast clouds have been noticeably improved with cloudy IR10.8 radiance assimilation that featured clusters of convection in TC eyewall. Results imply that the higher model top, careful bias correction and quality control each play a role in shortening the period of the initial convection spinup as well as placing storms closer to observations. Some examples of all-sky radiance assimilation will be discussed.
Assimilation of Satellite Soil Moisture Data Products from SMOPS in NCEP Global Forecast System

Weizhong Zheng\textsuperscript{a,b}, Xiwu Zhan\textsuperscript{c}, Jicheng Liu\textsuperscript{c,d}, Michael Ek\textsuperscript{a}

\textsuperscript{a} NOAA/NCEP/EMC, USA, \textsuperscript{b} IMSG, USA, Weizhong.Zheng@noaa.gov, \textsuperscript{c} NOAA/NESDIS/STAR, USA, \textsuperscript{d} GMU, USA

Global soil moisture data products have been continuously generated from existing and planned satellite microwave sensors. They could be used for initialization of soil moisture state variables in numerical weather, climate and hydrological forecast models. A global Soil Moisture Operational Product System (SMOPS) has been developed at NOAA/NESDIS to continuously provide global soil moisture data products to meet NOAA/NCEP's soil moisture data needs. To assimilate the soil moisture data products in improving forecasts of the NCEP Global Forecast System (GFS), the Ensemble Kalman Filter (EnKF) data assimilation algorithm has been implemented in the GFS. In this study, the quality of the soil moisture data products from SMOPS is examined against in situ measurements. The biases of the soil moisture retrievals from the Noah land surface model simulations in GFS are corrected before assimilating the retrievals into the model. Experiments with full cycle runs of the EnKFGFS and NCEP Gridpoint Statistical Interpolation (GSI) analysis system were performed for different seasons including seasons with potential freeze/thaw soil state transitions. The impacts of the soil moisture data assimilation on GFS estimates of soils moisture and energy fluxes, 2 meter surface air temperature and humidity, and on GFS precipitation forecasts were investigated. Results from this investigation together with the SMOPS data products and EnKFGFS systems will be presented.
Assimilation of Atmospheric Temperature and Moisture Soundings from AIRS for Hurricane Forecasts in regional NWP

Jing Zheng\textsuperscript{ab}, Jun Li\textsuperscript{b}, Jinlong Li\textsuperscript{b} and Zhiquan Liu\textsuperscript{c}

\textsuperscript{a}National Satellite Meteorological Center, China Meteorological Administration, China, Email: jingzheng.cma@gmail.com, \textsuperscript{b}Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin - Madison, USA, \textsuperscript{c}National Center for Atmospheric Research, USA.

The objective of this study is to investigate the impacts of AIRS soundings on hurricane forecasts. By using the three-dimensional variation (3DVAR) methodology, AIRS soundings are assimilated into the Weather Research and Forecasting model (WRF). Both single field-ov-view (SFOV) retrievals from UW/CIMSS and AIRS science team sounding product are tested in the assimilation. A series of cycling numerical experiments for Hurricane Ike (2008), Hurricane Irene (2011) and Typhoon Saola (2012) are conducted. The control experiments include the conventional observations. Results show improvements of hurricane track due to assimilating the AIRS temperature soundings. The potential impact of assimilating moisture information is also discussed.
Assessing the impact of lightning observations in a hybrid data assimilation system

Karina Apodaca\textsuperscript{a}, Milija Zupanski\textsuperscript{a}, Mark DeMaria\textsuperscript{b}, John A. Knaff\textsuperscript{b}, and Lewis D. Grasso\textsuperscript{a}

\textsuperscript{a} Cooperative Institute for Research in the Atmosphere, Colorado State University, USA, karina.apodaca@colostate.edu, \textsuperscript{b} NOAA Center for Satellite Research and Applications, USA

In this study, a methodology to assimilate real lightning data using a hybrid ensemble-variational data assimilation system is presented. Lightning observations are assimilated into a cloud-resolving scale numerical weather prediction model to correct the intensity and location of deep convection. The Maximum Likelihood Ensemble Filter (MLEF), interfaced with the Advanced Research WRF core of the Weather Research and Forecasting (WRF-ARW) model is employed to assimilate ground-network lightning data used as a proxy for the Geostationary Lightning Mapper (GLM) that will be aboard the next generation of NOAA geostationary satellite (GOES–R). The lightning Forecast Algorithm described in McCaul et al. (2009) is used as a lightning observation operator.

Regional data assimilation experiments are conducted in applications for severe weather. Results that highlight the impact on storm dynamics at the initial time and short-term forecasts are presented. In addition, the results of assimilation of combined lightning and NCEP operational observations are shown.

References
Impact of Observations on High-Resolution Analyses and Forecasts over the Dallas-Fort Worth Testbed

Lee Carlaw\textsuperscript{a,b}, Jerald Brotzge\textsuperscript{a}, and Frederick Carr\textsuperscript{a,b}

\textsuperscript{a}Center for Analysis and Prediction of Storms (CAPS), University of Oklahoma
\textsuperscript{b}School of Meteorology, University of Oklahoma

In a recent report, the National Research Council (NRC) noted that the current state of mesoscale observations in the U.S. are inadequate to satisfy the needs for producing high-resolution analyses and forecasts of high-impact weather events (National Academy of Sciences 2009). The report recommended the development of a distributed adaptive “Network of Networks” (NoN) in which data from the nation’s observing systems, run by a consortium of government and private sector data providers, are partially centralized to form a single, multi-purpose, nationwide mesoscale observing network. To better understand the contribution and impact of each new observing system on weather analysis and prediction, the NRC report also recommended the development of research testbeds. The research testbed provides a platform to test and optimize when and how data from each system can best be used for improved weather operations.

By December 2013, the Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) will have installed an 8-radar, NoN testbed across the Dallas – Fort Worth (DFW) Metroplex. Known as the DFW Urban Demonstration Network, data will be collected in real-time from a consortium of local data providers, and a suite of value-added products, including analyses and forecasts, will be generated and disseminated to end-users.

In this study, the authors examine the impact of assimilating observations from the DFW Network for producing high-resolution (400-m) analyses and forecasts. Using the Center for Analysis and Prediction of Storms’ (CAPS) Advanced Regional Prediction System (ARPS) and its three-dimensional Variational Analysis package (3DVAR), a series of experiments were performed in which data sources were withheld from initial analyses. In particular, the relative impacts of assimilating observations collected from Global Science and Technology, Inc. (GST), which has mounted atmospheric sensors on transportation fleets around the country, and Earth Networks, which deploys atmospheric sensors at schools and public venues, are investigated. Primary verification of near-surface weather is performed against an independent subset of nine ASOS stations and the National Mosaic and Multi-Sensor Quantitative Precipitation Estimate (NMQ) dataset.

Assimilation of Multifunction Phased Array Radar data for the Prediction of Thunderstorms during the May 24th, 2011 Oklahoma Tornado Outbreak

Guoqing Ge, Ming Xue, Jidong Gao, Louis Wicker and Pamela Heinselman

*Center for Prediction and Analysis of Storms, University of Oklahoma, USA, geGuoqing@ou.edu, School of Meteorology, University of Oklahoma, USA, NOAA National Severe Storm Laboratory, USA

The NWRT (National Weather Radar Testbed) MPAR (Multifunction Phased Array Radar) has the ability to scan thunderstorms in high-temporal-resolution, and provides rapid volumetric updates about every 1 minute. The high-temporal-resolution radar data has very advantageous benefits in monitoring storm evolution and issuing storm warnings compared to current operational WSR-88D radar data [1][2][3]. Assimilation of such high-temporal-resolution radar data into an NWP model to improve the forecast of storms is an ongoing research topic and a very challenging problem. Yussouf and Stensrud [4] have demonstrated in their EnKF (Ensemble Kalman Filter) OSSEs (Observing System Simulation Experiments) that assimilating PAR (Phased Array Radar) observations every 1 minute for 15 minutes can produce better analyses and ensemble forecasts than assimilating WSR-88D radar data. Ge et al. [5] also showed in their variational OSSEs that for wind observations, 1-minute assimilation frequency produced better analysis than 5-minute or 10-minute frequency. However, it is still unknown in real case studies how the high-temporal-resolution MPAR data affects the data assimilation and the forecast of thunderstorms.

During the May 24th, 2011 Central Oklahoma Tornado outbreak, the MPAR scanned the storms in very high frequency. A three-dimensional variational data assimilation system (3DVAR) developed at the Center for Analysis and Prediction of Storms (CAPS) is used to assimilate this data into a storm scale non-hydrostatic NWP model—the Advanced Regional Prediction System (ARPS). Both reflectivity and radial velocity data will be assimilated. 3DVAR analyses will be produced every 1 minute and every 5 minutes using a cycling approach, where the ARPS model is used to integrate the 3DVAR analysis forward in time between data insertions. The initial model background state is provided by the NCEP NAM mesoscale forecast system to ensure that realistic environmental structures are given to the data assimilation system. The results from the 1-minute cycle and 5-minute cycle are compared to examine the impact of high-temporal-frequency data on storm-scale radar data assimilation and subsequent forecasts. It is expected that the high-temporal-resolution MPAR data can improve the data assimilation and the ensuing forecast.

References


Satellite cloud observations contain crucial information about convective activity and are therefore seen as important input parameters for convective scale data assimilation (DA). In current operational DA systems however, only thermal infrared and microwave radiance observations are assimilated and their use is often limited to clear-sky conditions, whereas visible and near-infrared radiances (which mainly deliver cloud information) are neglected due to the lack of suitable forward operators.

To address this shortcoming, a 1D forward operator for visible and near-infrared radiance observations from MSG-SEVIRI is currently developed in the framework of the Data Assimilation Branch of the Hans-Ertel-Centre for Weather Research at LMU München. A first version of the operator that is reasonably fast to perform assimilation studies has been completed and implemented in the pre-operational KM-scale Ensemble Data Assimilation (KENDA) system of DWD [1]. The operator simulates synthetic satellite images from COSMO-DE model output based on the discrete ordinate method to solve the radiative transfer equation.

To assess the operator accuracy, the 1D simulations have been compared to 3D Monte Carlo simulations. After including a suitable parallax correction to account for the slant satellite viewing angle, the difference between 3D and 1D results from 06 to 15 UTC in summer are typically less than 6% and the systematic difference is less than 1%. This is seen to be sufficiently accurate to assimilate such observations. For larger solar zenith angles, e.g. at 18 UTC, the difference becomes larger.

Based on this development, assimilation studies with the regional KENDA-COSMO system are conducted to assess the impact of such visible SEVIRI satellite observations, in particular with respect to clouds. First results show that the assimilation of these observations successfully modifies the cloud water content in the analysis. Besides the direct assimilation, such an operator is potentially also valuable to identify and address shortcomings of the model microphysics that lead to systematic errors in the representation of clouds in the model.

Variational Bias Correction of Conventional Observations

Dick Dee\textsuperscript{a}, Hans Hersbach\textsuperscript{a}, Lars Isaksen\textsuperscript{a}, Marco Milan\textsuperscript{b}, Paul Poli\textsuperscript{a}, Christina Tavolato\textsuperscript{b}, and Drasko Vasiljevic\textsuperscript{a}

\textsuperscript{a}European Centre for Medium-Range Weather Forecasts, United Kingdom, dick.dee@ecmwf.int, \\
\textsuperscript{b}Department of Meteorology and Geophysics, University of Vienna, Austria

Variational bias correction of observations (VarBC) was originally developed at NCEP as part of its Spectral Statistical Interpolation analysis system [1] and subsequently implemented in ECMWF’s Integrated Forecast System [2]. VarBC was designed to automate and optimize bias adjustments for the growing volume and variety of satellite radiance measurements that are used in global numerical weather prediction. It has also been successfully applied in modern reanalyses to improve the consistency and homogeneity of climate data sets [3].

This presentation will describe efforts at ECMWF to extend the VarBC approach to handle in-situ observations from conventional instruments. These include the development of temperature bias corrections for aircraft observations recently implemented in the operational forecast system. We will also discuss ongoing work in the reanalysis context to address biases in observations of wind- and temperature from early radiosondes, and surface pressure observations from land stations, ships, and buoys.

References:

We present recent efforts supported by the Joint Center for Satellite Data Assimilation (JCSDA) to advance and increase passive microwave satellite observations assimilated within the GSI analysis system used to initialize both the Global Forecast System (GFS) model and regional Hurricane WRF (HWRF) model at the National Oceanic and Atmospheric Administration (NOAA). Specifically, the use of a 1d-variational (1dvar) preprocessor within the GSI will be discussed. The 1dvar preprocessor is applicable to current and future microwave satellite sounders and imagers including those from POES and MetOp AMSU-A and MHS, NPP/JPSS ATMS, DMSP F16-F20 SSMI/S, GCOM-W AMSR2, TRMM/TMI and GPM GMI. The capability of the 1dvar preprocessor (which applies over all-surfaces and in all-weather conditions) includes increased quality control of the microwave radiances to be assimilated, provides dynamic surface emissivity over all surfaces therefore allowing the extension of the microwave data assimilation coverage, and cloudy and rainy data assimilation through providing hydrometeor (cloud, rain, ice) information to the assimilation system. This 1dvar preprocessing increases the number and types of observations that can be assimilated. The information provided by the 1dvar preprocessor will help with the assimilation of surface sensitive channels over non-ocean surfaces as well as cloudy and rainy radiance assimilation. Advancement in the assimilation of these types of observations should have significant positive impact on both global NWP forecast and regional NWP along with tropical cyclone track and intensity forecasts. Current status of the implementation of the 1dvar preprocessor in the GSI will be shown, along with examples and benefits from the quality control information it may provide, followed by discussion of its overall utility in data assimilation.