Observation Target Regions for Improving NWP Tropical Cyclone Motion Forecasts: Comparison of Objective Sensitivity-Targeting Techniques

Brett Hoover – Space Science and Engineering Center (SSEC), University of Wisconsin – Madison
Chris Velden – Space Science and Engineering Center (SSEC), University of Wisconsin – Madison
Sharan Majumdar – University of Miami
Carolyn Reynolds – Naval Research Laboratory

To ensure maximum benefit from assimilating targeted observations, they must be deployed in locations that have the most relevance to a forecast feature of interest, such as the development of a tropical cyclone (TC). Several mathematical techniques have been designed to identify these 'sensitive' regions for targeting. In this study, a comparison of some of these techniques is performed to identify their respective sensitive regions, and to examine the impact of perturbations to the flow in these regions on TC steering for typhoons observed during the T-PARC and TCS-08 reconnaissance mission experiments. The first sensitivity technique explored here uses the adjoint of an NWP model to directly produce sensitivity of a response function defined for the steering of the TC. A second method uses an adjoint to compute singular vectors, which are initial condition perturbations that will grow most rapidly for a given (energy) metric and lead-time. Third, the ensemble transform Kalman filter (ETKF), which produces an estimate of where observations will minimize forecast error variance, is used. Questions to be considered include: What differences (if any) appear in the target regions chosen by each technique, and can they be related to differences in their respective methodologies? How do perturbations to the initial conditions in regions of strong sensitivity evolve in the model simulation to impact steering? Do any of these techniques produce spurious target regions, or does one of them miss an important target region discovered by another?

Estimation of linear observation impact and its applications

Toshiyuki Ishibashi
Meteorological Research Institute, Japan
E-mail: ishibasi@mri-jma.go.jp

ABSTRACT

In data assimilation systems (DASs), the effect of each assimilated observation dataset on an analysis field is one of the main factors in determining analysis and succeeding forecast accuracy. We call the effect the linear observation impact, which is fully determined by the Kalman gain. However, the Kalman gain is never constructed explicitly in variational DASs. Therefore, the estimation of the linear observation impact is a difficult problem. In this study, we analyze linear observation impacts using two methods, the adjoint-based method (Baker and Daley 2000, Langland and Baker 2004, and Errico 2007) and the tangent linear approximation based method (Ishibashi 2011).

Firstly, the adjoint-based method is implemented to the JMA global 4D-Var DAS. One-month long experiments of the observation impact estimation (using a dry total energy norm and 15 or 27 hour forecasts) show that almost all observation data contribute forecast error reduction in average, and this result is consistent with those of past OSEs in JMA. However, the experiments show that the impact of a total satellite radiance data is about the same magnitude as that of radio sonde data. This result implies that there is still many room for improvement of the forecast accuracy by improving usage of the radiance data, since, in previous studies in other NWP centers shows larger impacts from radiances (Cardinali 2009). We also find impacts of water vapor channel radiances increase in case of using a norm including humidity energy, and the method can detect wrong observation data which are given artificially deflated (too small) observation error settings.

Secondly, we construct the tangent linear approximation based method. The method estimates the linear observation impacts as a partial analysis increment vector that is generated by each observation dataset. The method enables us to see how the Kalman gain transforms information of observations into analysis increments.

In the workshop, applications of these methods for a design of an optimal observation system and an optimization of covariance matrix (Daescu 2008, Daescu and Todling 2010) will also be discussed.

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Satellite impact to short-range global forecast using the adjoint-based sensitivity method

Sangwon Joo[1], John Eyre[2] and Richard Marriott[2]

[1] Korea Meteorological Administration; [2] Met Office, UK

ABSTRACT

The volume of satellite data assimilated in an operational NWP system has increased dramatically with the help of advanced data assimilation methods. However it is still a challenge to add more satellite information (e.g. radiances over land) in many operational centres. It is also necessary to evaluate the impact of various subsets of satellite data for a better use of this information in NWP.

Adjoint-based sensitivity methods can produce observational impacts that are easily aggregated by various subsets such as observation method, time, location, channels and so on. With this capability the method is very useful for evaluating the impact of satellite data which contain lots of channels and strongly depend on the observational conditions.

In this presentation, the observation impact of satellite data used in the Met Office operational NWP system is evaluated depending on various subsets such as observation technique, platform, instrument, and so on, using the adjoint-based sensitivity tools that have recently been developed at the Met Office. Specifically the impact of IASI data over land is investigated in detail to find out how to use these data more effectively within the Met Office global NWP system.

Use of DFS to estimate observation impact in numerical weather prediction. Comparison of observation impact derived from OSEs and DFS results.

Cristina Lupu (ECMWF), Pierre Gauthier (UQAM) and Stephane Laroche (Environnement Canada)

In this study, the DFS derived from the a posteriori statistics to estimate the amount of information brought by the assimilation of the observations, is compared to the observation impact as derived by the OSEs performed at the Meteorological Service of Canada. In particular, the influence (DFS) of the main observing networks in three sub-regions of North America (Canadian Arctic, Canada and continental United States) is discussed and compared with the observation forecast impact derived from the OSEs where aircraft or radiosonde data are removed. The change of the DFS distribution due to the observation removal or to different weather regimes is also analysed. The DFS distribution among the different observation types assimilated and the impact of the same observations on the short range forecast is proved to be correlated.

A similar study has been also performed at ECMWF to assess the impact of all-sky SEVIRI radiances from Meteosat-9. In particular, recent impact results on the assimilation of all-sky radiance products from Meteosat-9 SEVIRI observations into the ECMWF four-dimensional variational assimilation will be presented in terms of OSE and DFS diagnostics.

Targeted Observations for Improving Numerical Weather Prediction: An Overview

Sharanya J. Majumdar, S. D. Aberson, C. H. Bishop, C. Cardinali, J. Caughey, A. Doerenbecher, P. Gauthier, R. Gelaro, T. Hamill, R. Langland, A. Lorenc, T. Nakazawa, F. Rabier, C. A. Reynolds, R. Saunders, Y. Song, Z. Toth, C. Velden, M. Weissmann, and C. C. Wu

“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 of importance to society. Examples include dropwindsondes launched from aircraft or balloons, additional rawinsonde ascents, remotely sensed observations, 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 decade, 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 here. Based primarily on a review by the WMO / THORPEX Data Assimilation and Observing Systems Working Group, recommendations are made to the community for the use of targeted observations in the future to maximize the impact on forecasts.

On the Role of NWP Impact Studies to Support the Evolution and Development of Current and Future Satellite Programmes

J. Schmetz [1], D. Klaes [1], P. Schlüssel [1], R. Stuhlmann [1], M. König [1], H. Bonekamp [1], M. Rattenborg [1], K. Holmlund [1], J. Daniels [2] and R. Borde[1]

EUMETSAT
[1] Darmstadt, Germany
[2] NOAA/NESDIS

Decisions on candidate missions to be flown on future operational meteorological satellites are usually supported by impact studies of pertinent satellite observations on numerical weather prediction. In particular this presentation will discuss the importance of such impact studies for the EPS-SG (EUMETSAT Polar System-Second Generation, i.e. the follow-on generation to the current Metop series). The paper will also address the need to foster the evolution of applications of future geostationary instruments, e.g. from the hyperspectral sounder on Meteosat Third Generation (MTG). This infrared hyperspectral sounder (IRS) will provide a better depiction of variations of humidity fields in space and time; it is argued that OSSEs with high-resolution, non-hydrostatic models will be an important element for the preparation of the use of the data.

It is recalled that the regular assessment of the impact of existing satellite products on NWP is a driver in a close cooperation between producers and users; as example we describe collaborative work aimed at improving the impact of atmospheric motion vectors (AMVs) on NWP as presented at the 11th International Winds Workshop in February 2012.

Finally the paper addresses the role of CGMS (Coordination Group for Meteorological Satellites) in coordinating the realisation of the global space-based observing system with satellites and specific instruments.

Abstract for "Fifth WMO Workshop on the Impact of Various Observing Systems on NWP", Sedona, AZ, 22-25 May 2012

Proposed Session -- Session 3: Specific scientific areas (including network design)

Opportunities and Challenges in Designing a Reference Upper-Air Network in Support of NWP

Authors -- J. Wang, G. Bodeker, S. Bojinski, D. Hurst, D. Seidel, D. Tan, P. Thorne, H. Vömel, R. Vose (Scientific Organizing Committee, GRUAN Workshop to Develop Network Design and Expansion Criteria)

[Note to Organizing Committee: This abstract is a bit unconventional in that we present no research directly relevant to the workshop topic. Rather we discuss aspects of the network design and expansion challenge that GRUAN faces and invite the assembled expert community to play an active role in designing a new reference upper-air network to enhance NWP.]

In response to calls, over many years, from the climate research and monitoring community, and under the auspices of the Global Climate Observing System (GCOS), a GCOS Reference Upper Air Network (GRUAN) has been initiated to provide observations of essential climate variables, from the surface into the stratosphere, and perhaps beyond. Several attributes distinguish GRUAN observations from operational upper-air observations, the main one being that GRUAN observations are required to be of reference quality. This means that each reported GRUAN measurement has had known biases removed and has an associated uncertainty value, based on thorough and quantitative characterization of all sources of measurement uncertainty. To ensure data consistency between GRUAN sites, bias correction and quality control of GRUAN measurements are performed by a single data processing center. GRUAN has focused to date on developing radiosonde-based reference upper-air temperature and upper-tropospheric humidity measurements, but plans include other atmospheric profile observations, including winds, ozone and other trace gases, aerosols, stratospheric water vapor, and radiation parameters.

Other important aspects of GRUAN are:

- adherence to GCOS climate monitoring principles agreed to by the United Nations Framework Convention on Climate Change;
- real-time and retrospective cross-validation of redundant measurements of the same parameter by different instruments and evaluation of measurement accuracies and drifts;
- commitment to a multi-decadal measurement programme;
- careful management of changes in instrumentation, observing practices, and data reduction methods to ensure a homogeneous climate record;
- strong commitments to coordinate with other networks and observing systems and to provide scientifically robust service to the user community.

GRUAN is currently in an implementation phase, 2009-2013, with an initial network of 15 sites, one of which is the Lead Centre at Lindenberg, Germany. GRUAN plans to expand to 35-40 sites after becoming operational in 2014. That expansion must be carefully planned to most effectively advance GRUAN's scientific objectives. Those objectives are to meet the needs of four primary user

communities: climate research and monitoring; satellite-based measurements; atmospheric process studies; and numerical weather prediction.

As we plan the expansion of GRUAN, a sound scientific basis for selecting new sites is needed, with detailed input from each of the four user communities. To organize that input, a June 2012 workshop is planned. In addition to clarifying the specific nature of the challenges of network expansion that GRUAN faces, this presentation constitutes an invitation for active participation by the NWP community in that workshop. We seek input from the NWP community both in the GRUAN expansion planning and in GRUAN overall. This could include observing system simulation experiments, both to design an upper-air climate network and to evaluate the value of accurate uncertainty measures on NWP. We will outline a more comprehensive set of questions needed to inform GRUAN expansion plans and potential benefits of GRUAN to NWP.

The impact of T-PARC special observations on typhoon track and mid-latitude forecasts

Martin Weissmann[1], Florian Harnisch[2], Sim Aberson[3], Carla Cardinali[4],Yeonhee Kim[5], Rolf Langland[6], Tetsuo Nakazawa[7], Yoichiro Ohta[8], Martin Wirth[2], Chun-Chieh Wu[9], Koji Yamashita[8],

[1]LMU Munich, Germany
[2]DLR Oberpfaffenhofen, Germany
[3]NOAA/AOML/Hurricane Research Division, USA
[4]ECMWF, Reading, UK
5National Institute of Meteorological Research, Korea
[6]NRL, Monterey, USA
[7]WMO, Geneva, Switzerland
[8]Japan Meteorological Agency
[9]National Taiwan University

A unique set of airborne observations including more than 1500 dropsondes, 2500 wind lidar profiles and 3900 lidar water vapor profiles was collected over the western North Pacific during the summer phase of the THORPEX Pacific Asian Regional Campaign (T-PARC) 2008. A number of data denial experiments with different numerical weather prediction models were performed to assess the impact of these observations on the forecast skill.

The benefit of airborne dropsonde observations was evaluated in the global models of ECMWF, JMA and NCEP and in the WRF limited area model. All models showed an improving tendency of typhoon track forecasts, but the degree of improvement varied from about 20-40% in NCEP and WRF to a comparably low influence in ECMWF and JMA. This is likely related to lower track forecast errors without dropsondes in the latter two models, presumably caused by a more extensive use of satellite data and 4D-Var assimilation at ECMWF and JMA compared to 3D-Var of NCEP and WRF. In the ECMWF system, dropsondes in a circular annulus of approximately 500 km from the typhoon center turned out to be most beneficial for typhoon track forecasts. Observations in the typhoon core and eyewall region and also observations in remote regions had a comparably small influence.

The wind lidar profiles were assimilated in the global models of ECMWF and NRL. Both models showed an overall beneficial influence of the observations. Additionally, the impact was quantified using the adjoint observation impact calculation. In the NRL system, the DWL impact per observation was higher than that of other wind observations, whereas in the ECMWF system, the DWL impact per observations was similar to other aircraft observations and lower than that of radiosondes.

The assimilation of water vapor lidar observations in the ECMWF system led to a reduction in the analysis error as demonstrated through a verification with independent dropsonde observations. The forecast influence of the humidity observations was found to be small in most cases, but the observations were able to affect the forecast considerably under certain conditions.

Further studies to assess observation impact are planned with the regional ensemble data assimilation and forecasting system KENDA/COSMO of the German Weather Service (DWD) as part of the recently founded Hans-Ertel-Center for data assimilation.

Observation system simulation experiments for the PREMIER mission

Yves J. Rochon, Jacek W. Kaminski, Sylvain Heilliette, Louis Garand, Jean de Grandpré, and Richard Ménard

Environment Canada

Abstract

Observation system simulation experiments (OSSE) were set up and applied for providing insight on the potential impact in numerical weather and ozone prediction of different observation sources. This was spurred through a study sponsored by the European Space Agency for providing insight on the potential impact of limb observations of temperature, water vapour and ozone from the PREMIER mission. PREMIER stands PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation. The simulated observations were calculated from the output of the ECMWF Joint OSSE T511NR free model nature run which serves as virtual truth. The observation types and characteristics of the control dataset are those of the real observations used in assimilation at Environment Canada. The observation noise levels applied to the control dataset were specified to produce statistical performance assessment results similar to those from the assimilation of real observations. The impact from real and simulated data sources was compared as a means to assess the realism of the OSSE system. Assimilation experiments with and without PREMIER data were conducted with the Environment Canada 3D-FGAT system using the Global Environmental Multiscale (GEM) forecast model with the addition of linearized ozone chemistry (LINOZ). A description of the simulations, an evaluation of the assimilation experiments and an assessment of impact of different data subsets are provided in this presentation.

Assimilation impact from satellite wind observations filling the gap at high latitudes

Louis Garand, Jian Feng, Yves J. Rochon, Sylvain Heilliette
Environment Canada

Atmospheric motion wind vectors (AMV) represent an important source of data for weather prediction. There is a gap of AMV observations in the latitude band 55-70 degrees created by the fact that neither geostationary (GEO) nor polar orbiting satellites can provide image triplets required for feature tracking. Canada is proposing the Polar Communications and Weather (PCW) mission defined by a 2-satellite constellation in a highly elliptical orbit. It will provide GEO-like imagery for the entire Arctic, thereby filling the aforementioned gap. Observation System Simulated Experiments (OSSEs) are conducted to evaluate the potential impact of PCW AMVs. A companion presentation (Rochon et al.) describes the OSSE set-up which considers all data types currently assimilated at Environment Canada. The OSSE system is also used to study the sensitivity to the assigned observation error and perturbation level of simulated AMVs. Recognizing that an inflated observation error is common practice, It nevertheless appears that the error should be adjusted as a function of local innovation statistics. The appropriateness of assimilating AMV data over land, where radiosonde and aircraft data are available, is also addressed.

The use of observation impact estimates to validate an OSSE

Ronald M. Errico and Nikki Prive

Goddard Earth Sciences Technology and Research,
Morgan State University, Baltimore, Maryland
Global Modeling and Assimilation Office,
National Aeronautics and Space Administration, Greenbelt, Maryland

For an observing system simulation experiment (OSSE) framework to be informative about behaviors of data assimilation systems applied to real observations, it is imperative that the framework be validated. This means that a suite of corresponding statistics computable in both real observation and OSSE contexts should be similar. One such set of statistics are observation impact estimates. Examination of these greatly expedites the OSSE validation process compared to the much more intensive process of examining pairs of OSEs, as traditionally conducted.

In this presentation, adjoint-derived observation impacts will be presented for a variety of OSSE validation experiments that have been conducted at the GMAO along with some other validation metrics. Preliminary results suggest that the OSSE framework validates sufficiently well for it to be useful in examining behaviors of present and proposed data assimilation algorithms and observing system designs.

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Adjoint-based impact studies of surface-based observation types at the UK Met Office

Richard Marriott

Met Office, UK

ABSTRACT

An adjoint-based tool for calculation of observation sensitivities and impacts has been developed recently by the Met Office. The tool has been applied to global 24-hour UM forecasts for a number of trial periods. These observation sensitivities and impacts have proven to be an important source of information in making decisions regarding prudent use of the UK and European observing budgets. In this talk I will present an outline of the UKMO observation sensitivities system, discussing ways in which it differs from other similar systems; summaries of the impacts of surface-based observation types in our forecast system; and two case-studies primarily motivated by our own budgetary considerations. The first of these case-studies looks at the impact of profiles of AMDAR observations over UK airports; the second looks at the impact of EUCOS E-ASAP radiosondes.