2.2 RECENT OBSERVING SYSTEM SIMULATION EXPERIMENTS AT THE NASA DAO

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1. INTRODUCTION

Since the advent of meteorological satellites in the 1960's, numerous experiments have been conducted in order to evaluate the impact of these and other data on atmospheric analysis and prediction. Such studies have included both OSE'S (Observing System Experiments) and OSSE's (Observing System Simulation Experiments). The OSE's were conducted to evaluate the impact of specific observations or classes of observations on analyses and forecasts. Such experiments have been performed for selected types of conventional data and for various satellite data sets as they became available. (See for example the 1989 ECMWF/EUMETSAT workshop proceedings on "The use of satellite data in operational numerical weather prediction" and the references contained therein.) The OSSE's were conducted to evaluate the potential for future observing systems to improve Numerical Weather Prediction (NWP) and to plan for the Global Weather Experiment and more recently for EOS (Atlas *et al.*, 1985a; Arnold and Dey, 1986; Hoffman *et al.*, 1990). In addition, OSSE's have been run to evaluate trade-offs in the design of observing systems and observing networks (Atlas and Emmitt, 1991; Rohaly and Krishnamurti, 1993), and to test new methodology for data assimilation (Atlas and Bloom, 1989).

2. EXPERIMENTAL DESIGN

Although there are many possibilities for how an OSE may be conducted, the most typical procedure is as follows: First a "Control" data assimilation cycle is performed. This is followed by one or more experimental assimilations in which a particular type of data (or specific observations) are either withheld or added to the Control. Forecasts are then generated from both the Control and experimental assimilations every few days (to achieve relative independence of the forecast sample). The analyses and forecasts from each assimilation are then verified and compared in order to determine the impact of each data type being evaluated.

Experiments performed in this manner provide a quantitative assessment of the value of a selected type of data to the specific data assimilation system (DAS) that was used. In addition, the OSE also provides useful information on the effectiveness of the DAS. This information can be used to improve the utilization of this and other data in the DAS, as well as to determine the value of the data.

The methodology currently used for OSSE's is very similar to that described above for OSE's. However, this methodology has evolved considerably since these experiments were first carried out in the 1950's and 60's (Arnold and Dey, 1986). The earliest simulation studies proceeded according to the following sequence of steps. First, an artificial history of the atmosphere was created by numerical integration of a model. Second, simulated "data" were created from the history by the addition of random variations to the history values for temperature, wind, and pressure. Third, the numerical integration that created the history was repeated, but with the meteorological variables in the model replaced by the simulated data at locations and times corresponding to the assumed pattern of observations.

OSSE's of this type were conducted by Charney *et al.* (1969), Halem and Jastrow (1970), Jastrow and Halem (1970, 1973), Williamson and Kasahara (1971), Kasahara (1972), Gordon *et al.* (1972), and others in preparation for the Global Weather Experiment. These studies provided an analysis of the Global Atmospheric Research Program (GARP) data requirements, the "useful" range of predictability, and the need for reference level data. From the results, it was concluded that the assimilation of satellite-derived temperature profiles meeting the GARP data specifications would yield a substantial improvement to the accuracy of numerical weather forecasts. A later study by Cane *et al.*(1981) using a modified OSSE procedure in-

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dicated similar potential for satellite surface wind data.

An examination of the underlying rationale for the early simulation studies (Jastrow and Halem, 1973), as well as a comparison of the results of the above studies with the results of subsequent real data impact tests (*e.g.* Halem *et al.*, 1982; Baker *et al.*, 1984) indicated several important limitations. The most important weakness stems from the fact that the same numerical model was used both to generate the simulated observations and to test the effectiveness of these observations. (This is referred to as the "identical twin" problem.) Other weaknesses relate to the model-dependence of the studies and the specification of observational errors as random. These weaknesses can lead to overly optimistic results and incorrect conclusions from an OSSE.

The current methodology used for OSSE's was designed to increase the realism and usefulness of such experiments (Atlas *et al.*, 1985b). In essence, the analysis/forecast simulation system consists of the following elements :

1. A long atmospheric model integration using a very high resolution "state of the art" numerical model to provide a complete record of the assumed "true" state of the atmosphere (referred to as the "nature run" or "reference atmosphere"). For the OSSE to be meaningful, it is essential that the nature run be realistic, *i.e.* possess a model climatology, average storm tracks, etc. that agrees with observations to within prespecified limits.

2. Simulated conventional and space-based observations from the nature run. All of the observations should be simulated with observed (or expected) coverages, resolution, and accuracy. In addition, bias and horizontal and vertical correlations of errors with each other and with the synoptic situation should be introduced appropriately. Two approaches have been used for this purpose (Atlas *et al.*, 1985b; Hoffman *et al.*, 1990). The simpler approach is to interpolate the nature run values to the observation locations and then add appropriate errors. The more complicated (and expensive) approach is to attempt to retrieve observations from the nature run in the same way as observations are retrieved from the real atmosphere.

3. Control and experimental data assimilation cycles. These are identical to the assimilation cycles in an OSE except that only simulated data are assimilated. In order to avoid the identical twin problem, a different model from that used to generate the nature run is used for assimilation and forecasting. Typically this model has less accuracy and resolution than the nature model. Ideally, the differences between the assimilation and nature models should approximate the differences between a "state of the art" model and the real atmosphere.

4. Forecasts produced from the Control and Experimental assimilations. As with the OSE's, forecasts are generated every few days to develop an independent sample. The analyses and forecasts are then verified against the nature run to obtain a quantitative estimate of the impact of proposed observing systems and the expected accuracies of the analysis and forecast products that incorporate the new data.

An important component of the OSSE that improves the interpretation of results is validation against a corresponding OSE. In this regard, the accuracy of analyses and forecasts and the impact of already existing observing systems in simulation is compared with the corresponding accuracies and data impacts in the real world. Ideally, both the simulated and real results should be similar. Under these conditions, no calibration is necessary and the OSSE results may be interpreted directly. If this is not the case, then calibration of the OSSE results can be attempted by determining the constant of proportionality between the OSE and OSSE impact as described by Hoffman *et al.* (1990).

3. RESULTS OF LIDAR WIND EXPERIMENTS

A series of observing system simulation experiments (OSSE's) are being conducted at the NASA Data Assimilation Office (DAO) in order to determine the potential impact of space-based lidar wind profiles in current data assimilation/ numerical weather prediction systems and to evaluate tradeoffs in lidar instrument design. In the first of these experiments, the nature run (reference atmosphere) was generated using an early version of the Finite Volume General Circulation Model (FVGCM) at .5 degree resolution, and the assimilation and forecast system was the current operational version of the GEOS 3 Data Assimilation System at 1 degree resolution. This nature run is substantially longer than earlier nature runs and covers a three and one half month period. In addition, the nature run contains very interesting and important meteorological features, including tropical cyclones and very realistic representation of atmospheric fronts and extratropical cyclone evolution.

Following a very detailed assessment of the realism of the nature run and the differences between the nature run model and the assimilation/forecasting model, the entire OSSE system was validated through a comparison of parallel real data and simulated data impact experiments. Then parallel assimilation experiments and fourteen five-day forecasts were performed with this system to evaluate the impact of idealized space-based lidar wind profiles. As in earlier OSSE's (Atlas, 1997, Lord et al., 2001), one of the major metrics for assessing the potential impact of lidar winds was the anomaly correlation for sea level pressure and 500 mb height forecasts. In addition, a number of additional metrics, such as impact on the central pressure and displacement of cyclones or the landfall of hurricanes was also evaluated.

The results of this evaluation showed a very substantial improvement in forecast accuracy resulting from the assimilation space-based lidar winds. In the Southern Hemisphere, average forecast skill was extended by 12 - 18 hours, while in the Northern Hemisphere, average forecast skill was extended by 3- 6 hours. This was associated with a meaningful (10%) reduction in position error for all cyclones averaged over the globe and all time periods. For very intense cyclones (those with central pressure less than 945 hPa), the reduction of position error exceeded 200 km. A meaningful impact on the prediction of hurricane landfall is shown in Figure 1, which illustrates the improvement in hurricane landfall prediction as a result of assimilating lidar data. This result was obtained for the first hurricane in the nature run. The predicted landfall position error for the two tropical cyclones to hit the U.S. mainland in the nature run was improved by approximately 150 miles for both storms. These results demonstrate considerable potential for space-based lidar wind profile measurements, however further experiments are needed to evaluate the specific characteristics of proposed lidars.

4. ACKNOWLEDGMENTS

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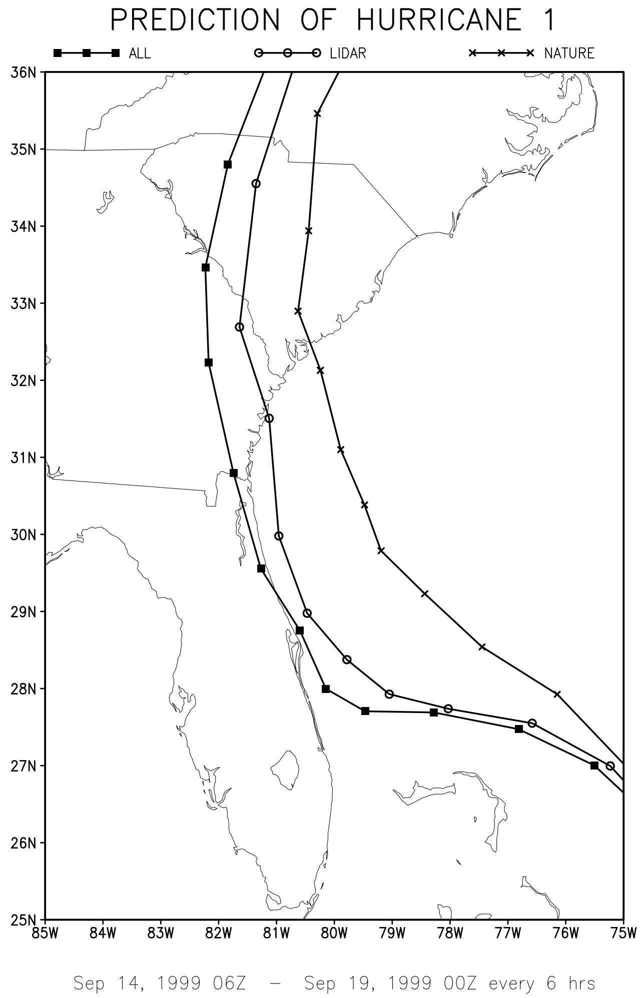

Figure 1 Lidar impact on hurricane track prediction.

- X's: nature track
- Squares: forecast beginning 63 h before landfall using current data
- Circles: improved forecast for same period using simulated lidar data