Impact of Doppler Wind Lidar Data on Hurricane Prediction

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Abstract: One of the most important applications of a space-based Doppler Wind Lidar (DWL) would be to improve atmospheric analyses and weather forecasting. Since the mid-1980s, Observing System Simulation Experiments (OSSEs) have been conducted to evaluate the potential impact of space-based DWL data on numerical weather prediction (NWP). All of these OSSEs have shown significant beneficial impact on global analyses and forecasts. In more recent years, a limited number of OSSEs have been conducted to evaluate the potential impact of DWL data on hurricane forecasting and to also evaluate the impact of real airborne DWL observations. These latest studies suggest that DWL can complement existing hurricane observations effectively and should contribute to improved hurricane track and intensity forecasting.

Keywords: DWL, OSSE, OSE, simulation experiments, hurricanes

1. Introduction

Winds are among the most important variables in the atmosphere. They transport all the other variables of the atmosphere and govern the exchanges of mass, energy, and momentum between the atmosphere and the underlying ocean and land surfaces. There is a substantial opportunity to improve numerical weather prediction (NWP) by better observing the global wind field. Currently, winds make up a very small fraction of the observations that are used in data assimilation systems. Many of the winds that are available are created by tracking features in the cloud or water vapor field. These atmospheric motion vectors are very valuable, but they are an indirect measurement and have inherent height uncertainties that make their use somewhat problematic. In contrast, Doppler Wind Lidars (DWLs) directly and very accurately measure the line-of-sight wind by observing the Doppler shift in the lidar signal returned by a volume of atmospheric scatterers. Baker et al. [1] provide an excellent description of the need for a DWL, a review of previous impact studies that used both simulated satellite and real-world aircraft-based data, and an overview of instrument concepts and their supporting technologies. Impact experiments with real data, termed Observing System Experiments (OSEs), are conducted with and without one observing system to quantify the impact of that observing system. Similar experiments with simulated data are termed Observing System Simulation Experiments (OSSEs). In OSSEs a long forecast is taken to be the ‘‘truth’’ or nature run.

The present study complements previous space-based DWL OSSEs by examining the impact of DWL observations on hurricanes and by beginning to evaluate the impact of having an existing DWL on NOAA’s Hurricane Hunter aircraft. The objectives of the OSSEs for hurricanes are to (1) evaluate the potential impact of proposed observing systems on hurricane track and intensity prediction, (2) evaluate trade-offs in the design and configuration of these observing systems, (3) optimize sampling strategies for current and future airborne and space-borne observing systems, and (4) evaluate and improve data assimilation and vortex initialization methodology for hurricane prediction.

2. Methodology

The methodology currently used for OSSEs is described in detail by Atlas [2] and 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"). Nature runs may be generated by either global or regional models or by embedding a regional model within a global nature.

(2) Simulated conventional and space-based observations from the nature run. These observations are simulated with realistic coverages and accuracies.

(3) Control and experimental data assimilation cycles, with and without the specific observing systems that are being evaluated.

(4) Forecasts produced from the Control and Experimental assimilations.

For the OSSE to be credible, it is essential that each of the components of the OSSE system be evaluated for realism and that the limitations of the system be defined. 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, calibration of the OSSE results can be attempted by determining the constant of proportionality between the OSE and OSSE impact.

3. Examples from OSSEs to Assess DWL Data

An extensive series of OSSEs has been conducted since the mid-1980s to evaluate the potential impact of space-based DWL on NWP. All of these OSSEs have shown significant beneficial impact resulting from the assimilation of DWL data. Additional OSSEs evaluated trade-offs in orbit altitude, laser power, coverage, and accuracy. Figure 1 presents two examples from the first global OSSEs to address hurricane

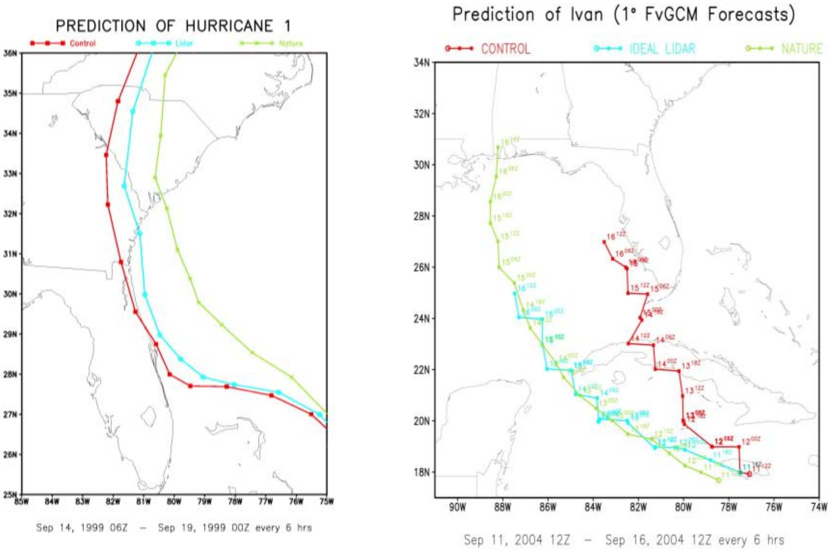

Figure 1. Illustrations of the potential impact of lidar winds in two early global OSSEs. Green (easternmost track): actual track from nature run. Red (westernmost track): forecast beginning 63 hours before landfall with all currently used data. Blue (middle track): improved forecast for same time period with simulated DWL data added.

forecasting. Here a significant impact on hurricane track prediction was observed. No similar negative impacts on hurricane track occurred in these experiments.

Figure 2 shows one example from a recent OSSE using a WRF 1-km resolution nature run embedded in an ECMWF global nature run. In this case, global assimilation of DWL data resulted in both improved hurricane track and intensity forecasts. Regional assimilation of DWL data in this case improved the intensity forecast substantially further, but did not improve the track forecast.

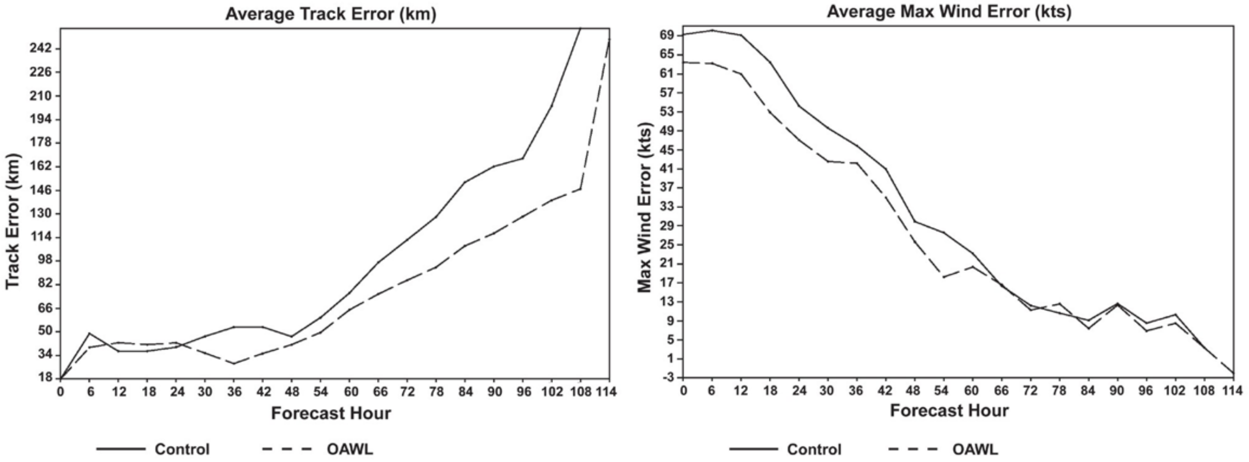

Figure 2. Impact of an Optical Autocovariance Wind Lidar (OAWL) on track and intensity forecasts in this case.

4. Current Work on Airborne DWL

An airborne DWL was flown for the first time in 2015 on the NOAA P3 Orion Hurricane Hunter aircraft into Atlantic Tropical Storms Danny and Erika. While technical challenges limited the operator's ability to use the DWL, good data were collected on the afternoon flight on August 26, 2015 into Tropical Storm Erika. The scanner was pointed down and forward (30° off nadir), sweeping out a curtain of data below the aircraft. The nearest DWL wind profiles were compared to winds from dropsondes throughout the flight. Profiles from both instruments showed qualitatively similar speed and structures in various regions of the storm. An exact replication of the dropsonde wind profiles is not expected, given that the DWL wind profiles represent a 1-km area average of the winds beneath the plane.

An impact study of the DWL observations was performed using the Hurricane Weather Research and Forecasting model. The experiment setup compared a "Control" which assimilated all observations typically available (tail Doppler radar, dropsondes, flight level, stepped frequency microwave radiometer, and satellite retrievals) to "Control+DWL" which added thinned DWL line-of-sight wind profiles. A comparison of the assimilated observations revealed that the DWL provided better coverage of the wind field, particularly on the western side of the storm which lacked deep convection. The DWL also provided wind measurements much closer to the surface (within 25 m) when compared to the tail Doppler radar observations (only to within 250-500 m). The DWL data provided the largest impact on the analysis wind field in the western portion of Erika (Figure 3). Boundary layer wind speed increased by as much as 8 kts in these regions. A smaller impact was also observed in the areas with good tail Doppler radar coverage, where a slight decrease in wind speed occurred. Unfortunately for this particular storm and time, there was no significant impact on the storm track and intensity forecast. The DWL is expected to be available for the 2016 hurricane field program, and future model impact studies will be performed after data collection.

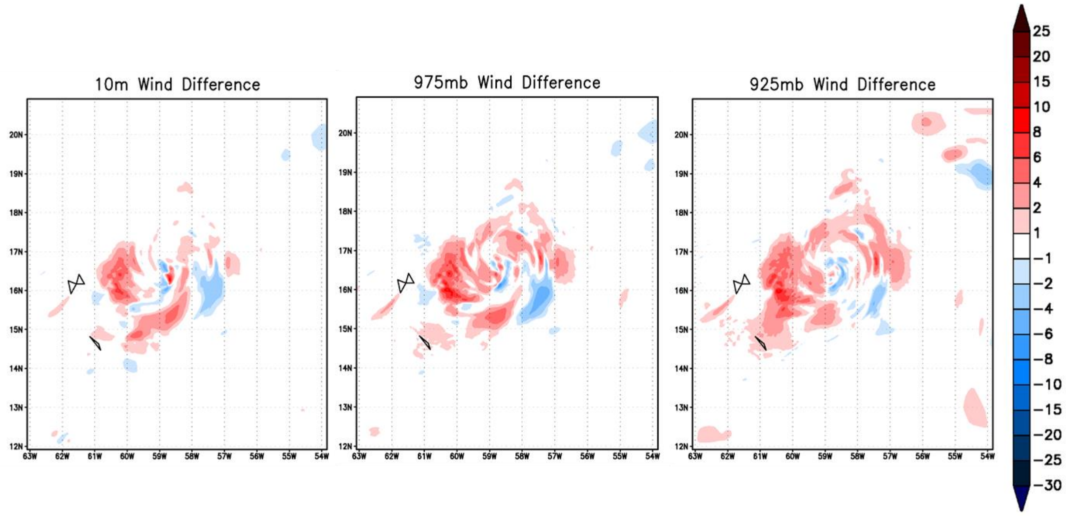

Figure 3. Difference in the analysis of the wind speeds (kts) at 10 meters, 975 mb, and 925 mb between the Control+DWL and Control experiments.

5. References

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