OSSE-BASED ASSESSMENT OF THE NWP IMPACT OF SPACE-BASED WIND LIDARS

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Abstract

The absence of vertically resolved wind observations over large portions of the globe is a well-recognized gap in the Global Observing System. One of the most promising paths toward closing this gap is to deploy one or more space-based Doppler Wind Lidars. The European Space Agency is planning to launch its ADM/Aeolus technology demonstration mission in 2013, and the US is planning to deploy its first DWL as one of NASA's Decadal Survey missions sometime after 2020. In support of the US mission definition effort, a testcbed has been established under the NASA-NOAA Joint OSSE collaboration to assess the NWP impact of various possible configurations of such a mission. Based on a comprehensive series of OSSEs we show the expected impact on NCEP forecast skill of simulated observations from various configurations of a space-borne hybrid (coherent and direct detections) lidar system. The experiments demonstrate the impacts of measuring one or two wind components, respectively as well as the impact of doubling the amount of data available.

INTRODUCTION

Observing System Simulation Experiments (OSSEs) have become the de facto standard method of evaluating the impact of space-based observing systems well in advance of their deployment. The methodology may be used even in advance of deciding to fund the development of new observing systems. The work presented in this paper represents a preliminary attempt to assess the expected impact of a hypothetical Doppler Wind Lidar (DWL) on the forecast skill of NCEP's Global Forecast System (GFS).

While several OSSE's related to Doppler Wind Lidars have been carried out in the past, the impact of the hybrid technology proposed for GWOS has never been assessed in and OSSE context. Nor has the NWP impact of any proposed DWL mission been simulated in the context of the modern (2011) global observing system that includes data types such as infrared and microwave satellite radiances and GPS radio occultation soundings.

The particular DWL system studied here is NASA's so-called GWOS (Global Wind Observing Sounder), which is tentatively planned to fly in the post-2020 time frame. GWOS is a hybrid system, applying both coherent and direct detection techniques to the Lidar returns. The coherent subsystem (Frehlich and Kavaya, 1991) provides wind observations by measuring the backscatter from atmospheric aerosol (primarily in boundary layer) and cloud particles, while the direct detection subsystem (Korb et al. 1992) makes its observations from molecular returns in regions of clear air, primarily in the middle and upper troposphere.

In contrast to ESA's ADM/Aeolus mission (Stoffelen et al., 2005), GWOS measures both horizontal wind components since it provides measurements along two non-parallel lines of sight for a given volume of air. Riishojgaard et al. (2004) argued that measuring both wind components may be very advantageous in terms of the impact on forecast skill. Earlier DWL concepts the two-component measurement through the use of a scanning mechanism (e.g. Emmitt and Wood, 1991), whereas GWOS uses four fixed telescopes mounted at horizontal angles of 45, 135, 225 and 315 degrees with respect to the velocity vector of the spacecraft and tilted downward at an angle of 45 degrees off nadir. The GWOS data acquisition, which is illustrated in Fig. 1 is such that the spacecraft first measures a given volume of air for instance through the fore right telescope. Approximately 80 seconds later, that same volume is measured again along a different line of sight through the aft right telescope, and the two measurements are then combined to derive the horizontal wind components under the assumption of zero mean vertical wind in the volume. Not shown in Fig. 1 is the left pair of telescopes, which takes a separate set of similar measurements on the opposite side of the orbital track. The second pair of telescopes is included mainly to improve the total coverage by helping to minimize the cross-track separation between the wind observations.

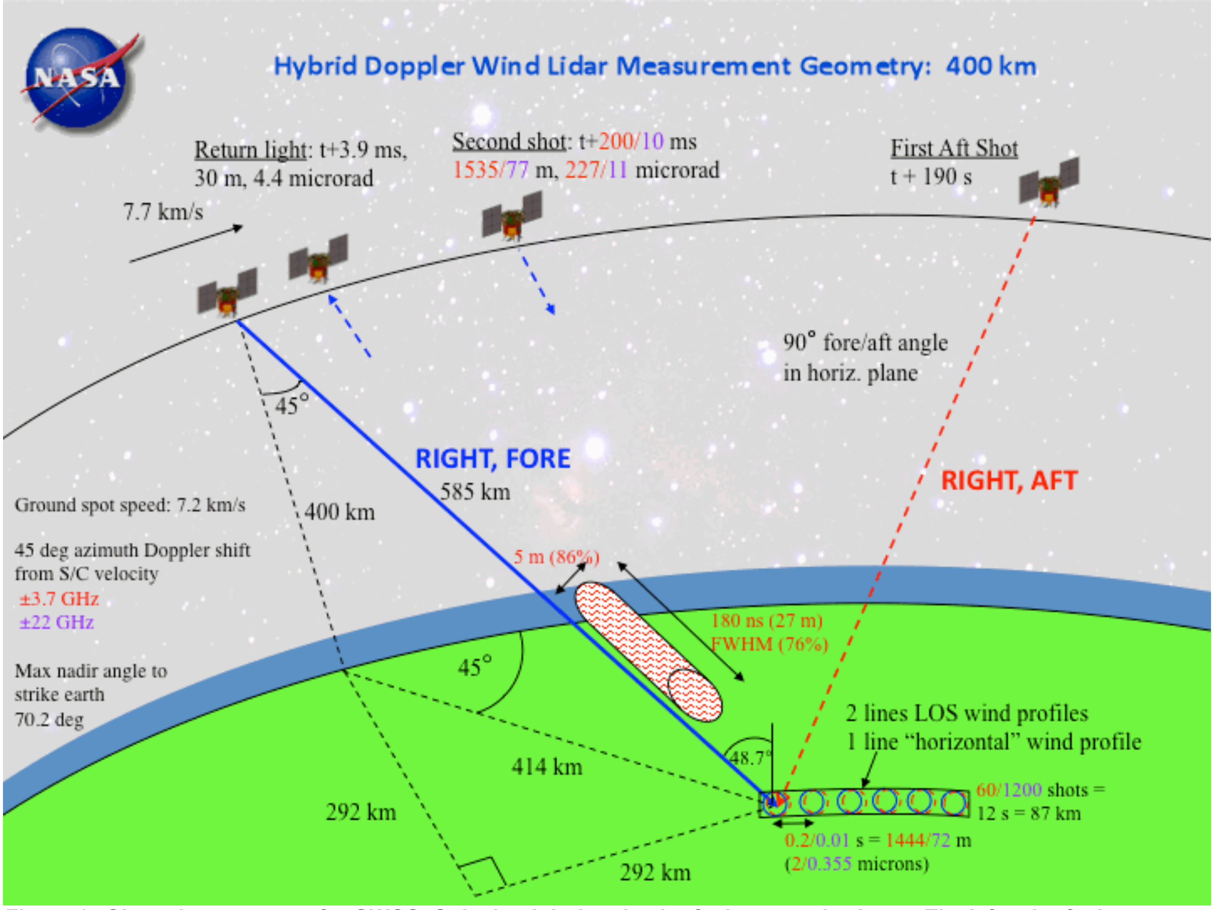

Figure 1: **Observing geometry for GWOS. Only the right-hand pair of telescopes is shown. The left pair of telescopes provides similar coverage on the opposite side of the satellite track.**

EXPERIMENTAL FRAMEWORK

The methodology of the experiments follows the OSSE design described e.g. by Atlas et al. (1984) and Arnold and Day (1986). A 13-month long Nature Run was provided by ECMWF using cycle 30r1 of the Integrated Forecast System (IFS) model with triangular truncation T511 (T511NR) and 91 levels in the vertical. The initial condition for the Nature Run was the ECMWF operational analysis valid at 1200 UTC on 1 May 2005, and the simulation extended through May 31 2006. Apart from the initial conditions, the only link to the “real” 2005-2006 period was the use of observed sea surface temperatures (SST) and sea ice coverage from this period as lower boundary conditions. In all other respects, the atmospheric state evolved in a manner that was different from that of the real atmosphere, but nonetheless meteorologically plausible. The Nature Run has undergone extensive validation and has been shown to have realistic hurricanes and mid-latitude cyclone statistics (Reale et al., 2007; Andersson and Masutani, 2010).

In the OSSE context, nature is defined by the Nature Run. Therefore, all types of observations must be simulated, irrespective of whether or not real-world observations of that type were available. The approach taken for the work presented here was simple: For observation types for which existing parallels existed (radiosondes, surface observations, aircraft data, existing satellite systems), observations were simulated at the times and locations for which actual observations were available in the corresponding real 2005-06 period, as recorded by the operational NCEP Global Forecast System.

The process of simulating the conventional observations (wind, temperature, surface pressure, humidity) thus basically amounted to sampling the Nature Run at the appropriate times and locations. The observation types, times and locations recorded in the NCEP operational database for the real 2005-06 time period was used to generate templates, which were then populated with information from T511NR to generate the simulated observations.

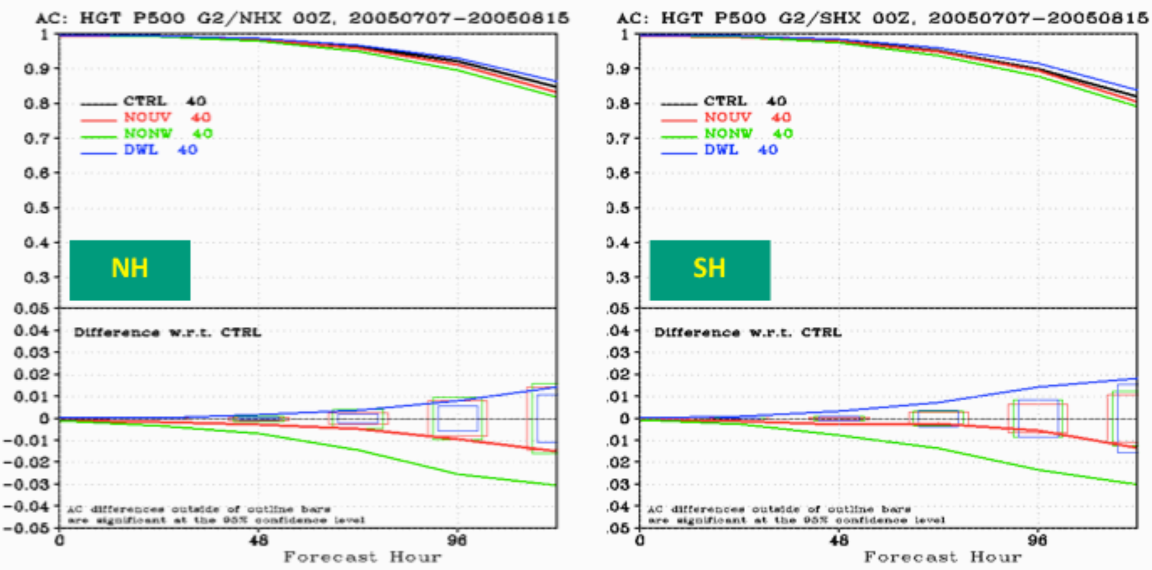

Figure 2: **Anomaly correlation coefficients in the NH (left) and SH (right) for the four experiments described in the text: CTLR (black), NOUV (red), NONW (green), and DWL (blue). Lower panel shows differences with respect to CTRL.**

Simulated satellite radiances were obtained by processing Nature Run profiles of temperature and humidity with the JCSDA Community Radiative Transfer Model (version 1.2.2). Land surface types and vegetation types provided by the Nature Run were used for the simulation, and data were simulated at the footprints and data densities used by the NCEP operational data assimilation. The simulation included radiances from AIRS, AMSU-A, AMSU-B, HIRS-2, HIRS-3, HIRS-4, MSU, MHS and the GOES sounder.

The simulation of DWL observations was conducted by Simpson Weather Associates (SWA), using the multi-agency funded Doppler Lidar Simulation Model (DLSM) described by Wood et al. (2000). Both direct and coherent detection returns were simulated.

The data assimilation/forecast experiments were conducted using the Dec 2009 version of the NCEP Global Data Assimilation System (Kleist et al., 2009).

RESULTS

First, a series of calibration experiments were carried out, in which forecasts done with simulated data were compared to forecasts done for real-world situations to ascertain that the OSSE system had a realistic level of overall skill. These experiments are not shown here.

Next, a control experiment was performed: a cycling data assimilation run extending over a spin-up period from July 1 through July 6, followed by an experimental period from July 7 through August 15. This provided a 40-day experimental period over which diagnostics were calculated. During the experimental period, five-day forecasts were launched each day at 00 Z.

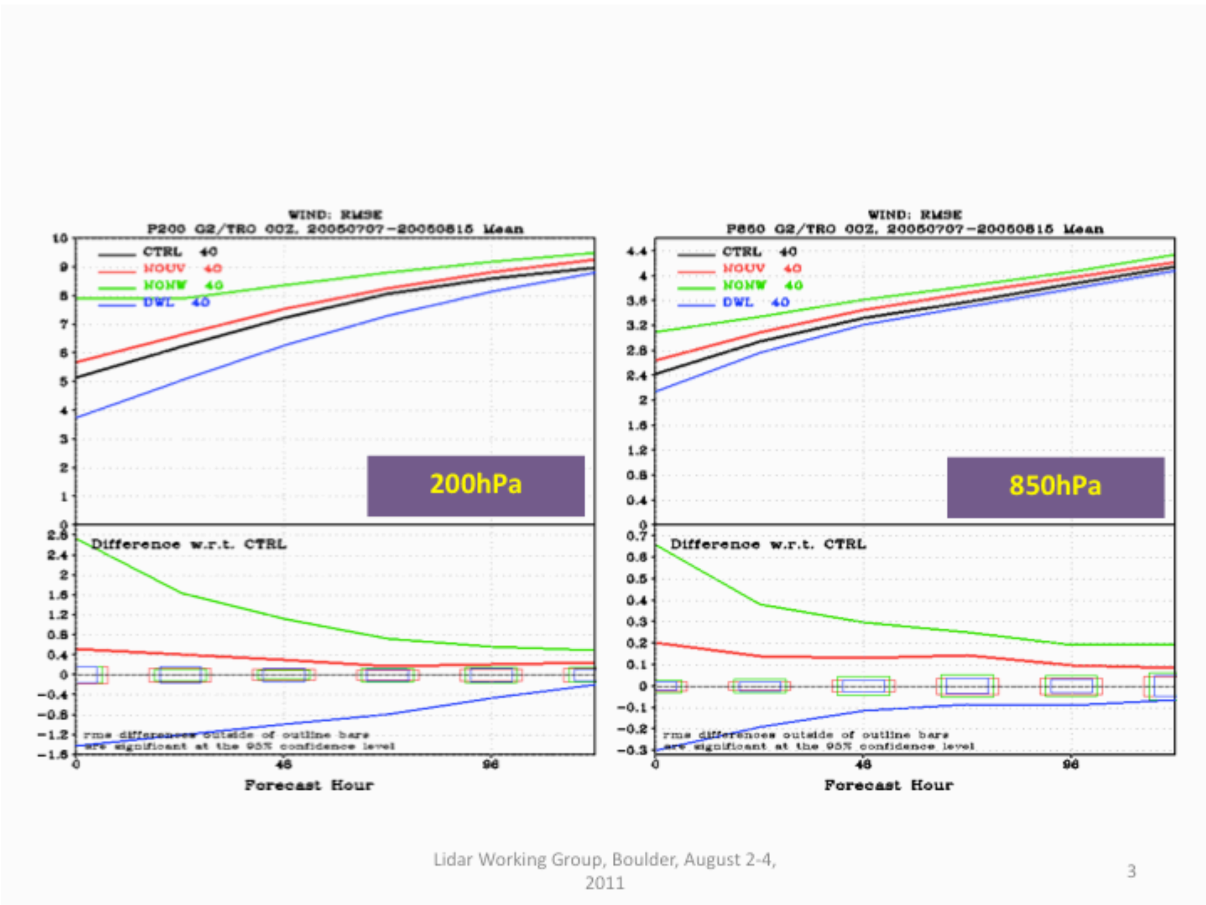

Figure 3: **Root Mean Square errors in the tropics at 200 hPa (left) and 850 HPa (right) for the four experiments described in the text: CTLR (black), NOUV (red), NONW (green), and DWL (blue). Lower panel shows differences with respect to CTRL.**

In the following step, a set of three perturbation experiments was done: 1) A run ("NOUV") from which all radiosonde, pilot balloons and dropsonde observations were removed. 2) A run ("NONW"), in which all wind observations were withheld. 3) An experiment ("DWL") in which simulated GWOS observations were added to the observations used for the control run. The experimental setup is consistent with the way the system is used in NCEP operations, except that model resolutions of T126 and T382 were used rather than the current (October 2011) operational resolution of T574. Only results from the higher resolution (T382) experiments are shown here.

Fig. 2 shows 500 hPa anomaly correlation for all four experiments in the Northern Hemisphere (left), and the Southern Hemisphere (right). All verification is done against the nature run, and the lower plot in all four panels shows differences in skill with respect to control run. Differences that are outside the errors bars for the respective color are statistically significant at the 95% level. We see that elimination of all wind observations leads to a very significant decrease in skill by the measure shown here (NOUV and NONW). We also see that the addition of the simulated lidar wind observations leads to a statistically significant increase in AC score at day five (120 h) of approximately 1.5 points in the northern hemisphere and approximately 2 points in the southern hemisphere.

Tropical RMS wind errors for the four experiments are shown in Figure 3. The impact of the simulated lidar wind observations in the tropics is initially very large, especially at the 200 hPa level. The 850 hPa level is more strongly influenced by the lower boundary conditions and due to the nature of the measurement, fewer lidar wind observations are available at this level. However, as also seen in other data impact experiments, the impact tends to decrease rapidly over time at either level. This behavior is typical for the tropics and it illustrates the general problem of information retention and hence limited forecast skill in the tropics that is typical of many global NWP systems.

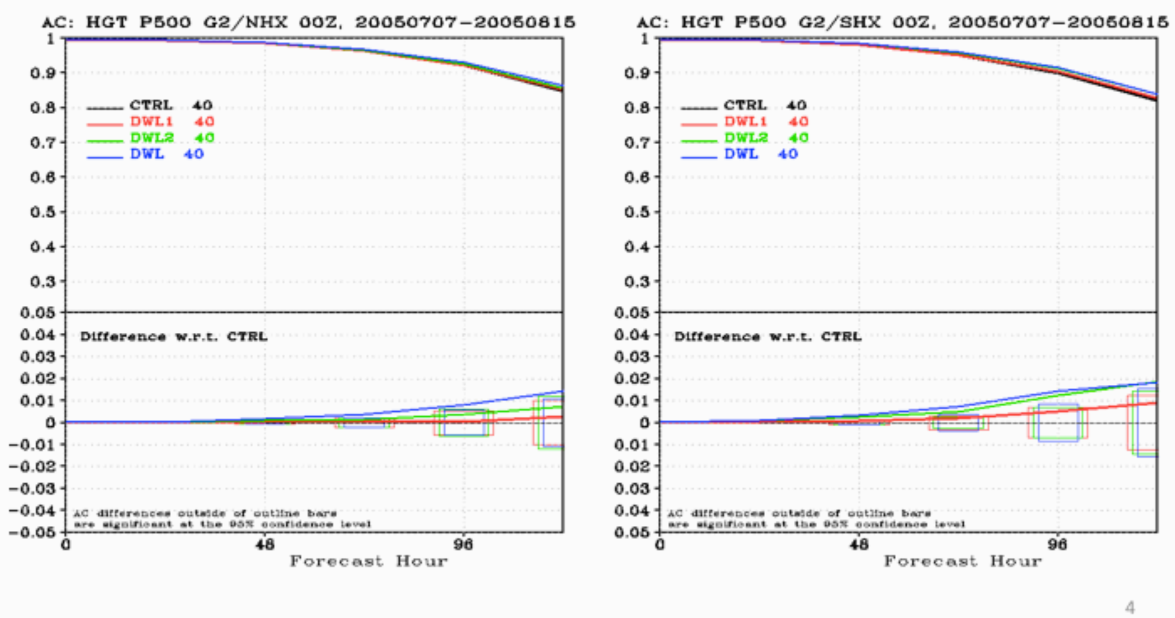

Figure 4: **Anomaly correlation coefficients for 500 hPa geopotential heights in the NH (left) and SH (right) for the following four experiments described in the text: CTLR (black), DWL1 (red), DWL2 (green), and DWL (blue). Lower panel shows differences with respect to CTRL.**

As mentioned in the introduction, the GWOS configuration contains four independent telescopes in order to increase the data coverage and to provide measurements of both horizontal wind components. The final set of experiments discussed in this paper was aimed at assessing the impact of having one, two and four telescopes available. The experimental framework was identical to the one described above. Sample results from the following four experiments are shown in Figure 4: 1) CRTL, the control experiment using all observations used in operations. 2) DWL1, a run in which DWL observations taken from one telescope one were added to the observation used for the control run. 3) DWL2, in which observations from both telescopes on the right side of the spacecraft were added to the control. 4) DWL, in which the full set of GWOS data were added to the control. The CRTL and DWL experiments are the same experiments discussed above and shown in Figures 2 and 3.

Both panels in Figure 4 show that more wind observations lead to larger impacts, which is to be expected since even the four-telescope configuration still provides only a relatively sparse set of profiles. However, the progression of impact from one experiment to the next is interesting. In both hemispheres, the impact of having two telescopes is more than twice as large as the impact of the single-perspective data. In the SH, it even approaches the magnitude of the four-telescope impact for this particular experimental period. While we stress the preliminary nature of these results, they do support the hypothesis of Riishojgaard et al. (2004) that a dual-perspective instrument would be significantly more beneficial to NWP than to single-perspective instruments observing along parallel directions.

SUMMARY AND CONCLUSIONS

We have presented a new OSSE framework developed by NASA, NOAA and JCSDA with help from ECMWF, and we have shown examples from the first set of Doppler Wind Lidar impact experiments carried out with this system. Any assessment of the impact of hypothetical observations in the context of future forecasting and observing systems is bound to be speculative to some extent. While not perfect, the OSSE methodology offers a rigorous, quantitative way of making such an assessment, using today’s best knowledge of modeling, observing and data assimilation methodology. Within the limitations inherent in the OSSE design, both the general case for adding more wind observations to improve forecast skill and the specific case for a GWOS-like DWL mission appear to be well supported by our experiments. The NOUV and NONW experiments both show a significant negative impact of withholding wind observations, and the additional skill shown in the DWL experiment indicates that the GOS is far from saturated with wind measurements. In addition to highlighting the benefits from increased data coverage, the progression in skill from DWL1 to DWL2 also shows that two perspectives may be preferable to single line of sight winds.

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