OBSERVING SYSTEM SIMULATION EXPERIMENTS FOR A SPACE-BORNE DOPPLER WIND LIDAR IN THE JOINT CENTER FOR SATELLITE DATA

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Abstract

The absence of vertically resolved wind observations over large portions of the globe is a well-documented shortcoming of the Global Observing System. While AMVs provide very good horizontal coverage of single-level wind observations over most of the globe, one of the most promising paths toward obtaining vertically resolved wind information is a space-based Doppler Wind Lidar. The European Space Agency will launch its ADM/Aeolus DWL technology demonstration mission in 2014, and the US is planning to deploy its first DWL system as one of NASA's Decadal Survey missions sometime after 2020. The NASA-NOAA Joint Observing System Simulation Experiment (OSSE) system has been used to assess the expected impact on numerical weather prediction skill of various possible configurations of this mission. We report on a series of experiment undertaken with this system in the expected impact on NCEP forecast skill of a hypothetical DWL system was simulated. The experiments show the respective impacts of measuring one or two wind components as well as the impact of increasing the horizontal data coverage.

INTRODUCTION

Observing System Simulation Experiments (OSSEs) have become the de facto standard experimental framework used for evaluating the impact of space-based observing systems well in advance of their deployment. The methodology can be used even prior to making the decision on whether or not to fund the development of a given new observing system. The work presented in this paper represents a preliminary attempt to assess the expected impact of a potential future US Doppler Wind Lidar (DWL) satellite system on the forecast skill of NCEP's Global Forecast System (GFS).

While several OSSE's for candidate DWL systems have been carried out in the past, the impact of the so-called hybrid DWL system studied here has never been assessed using this methodology. Nor have DWL OSSEs been performed with a modern, radiance-based assimilation system and in the context of the current (2012) state of the Global Observing System.

The particular DWL system studied here is NASA's so-called GWOS (Global Wind Observing Sounder) concept developed in response to the NRC Decadal Survey in 2007. 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) that includes a single fixed telescope and therefore only measures the projection of the wind vector onto to the line of sight (boresight) of that telescope, GWOS data can be used for estimating both horizontal wind components since it provides measurements along two orthogonal lines of sight for a given volume of air. Riishojgaard et al. (2004) argued that measuring both wind components are likely to substantially increase the impact on NWP skill. Earlier DWL concepts achieved the full vector measurement by using a scanning mechanism (e.g. Emmitt and Wood, 1991), whereas the GWOS concept includes four fixed telescopes mounted at horizontal angles of 45, 135, 225 and 315 degrees with respect to the velocity vector of the spacecraft, and each tilted downward at an angle of 45 degrees off nadir. The GWOS data acquisition pattern, which is illustrated in Fig. 1, is set up such that the spacecraft first measures the radial velocity of a given volume of air in the atmosphere through the fore right telescope. Approximately 80 seconds later, the radial velocity of 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.

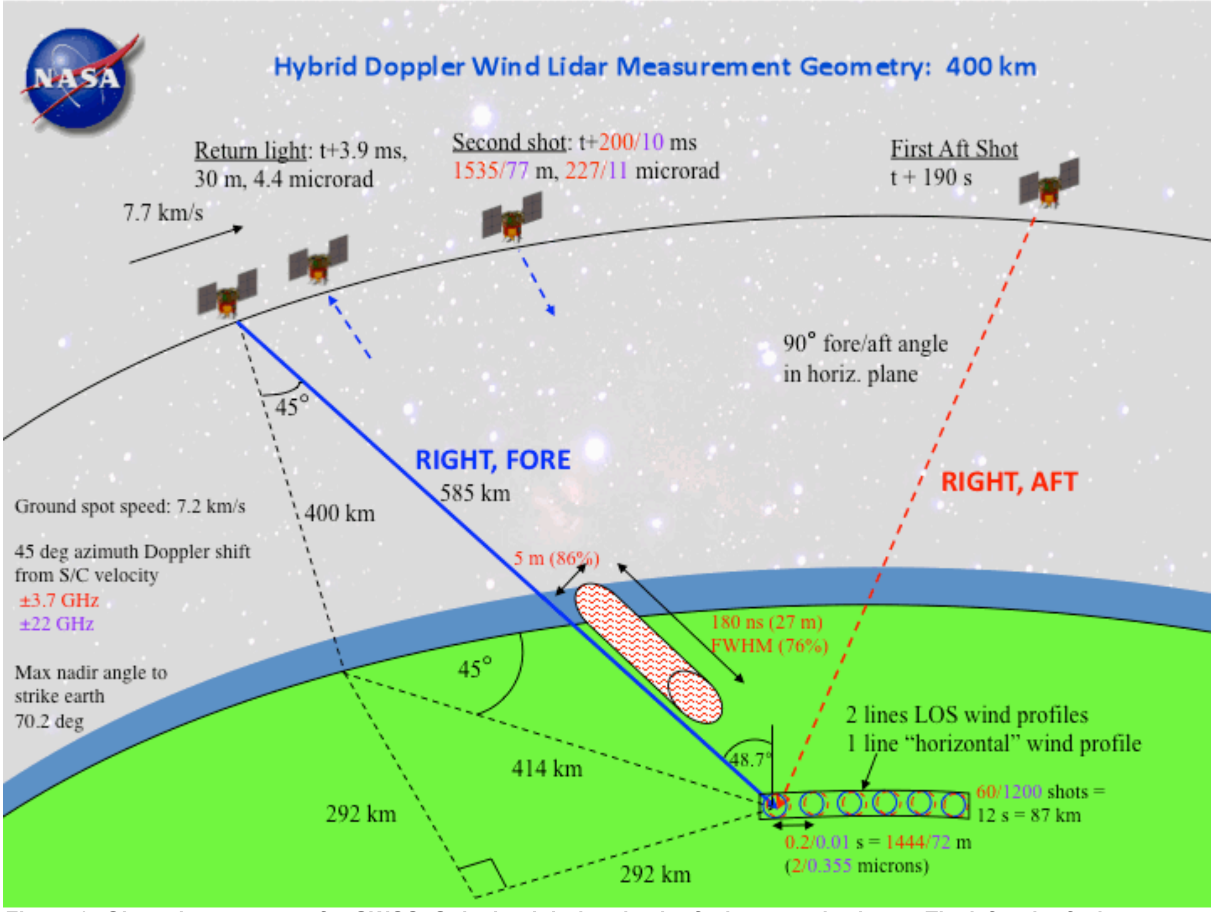

Figure 1: **Observing geometry for GWOS. Only the right-hand pair of telescopes is shown. The left pair of telescopes provides similar measurements on the opposite side of the satellite track in order to improve the total horizontal coverage.**

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 and 91 levels in the vertical. The initial condition for the Nature Run, henceforth referred to as T511NR, was the ECMWF operational analysis for 1200 UTC on May 1 2005, and the simulation extended through May 31 2006. Apart from the initial conditions, the only link to the “real” 2005-2006 atmospheric dynamics was through the use of observed sea surface temperatures (SST) and sea ice coverage as lower boundary conditions. In all other respects, the atmospheric state of the T511NR was left free to evolve in a manner that is different from that of the real atmosphere, but nonetheless meteorologically plausible. The T511NR has undergone extensive validation and has been shown to have realistic hurricane tracks and structures (albeit at unrealistically low intensities) and mid-latitude cyclone statistics (Reale et al., 2007; Andersson and Masutani, 2010).

In the OSSE context, the “true” state of the atmosphere is defined by the Nature Run. Therefore all types of observations to be used for the data assimilation/forecast experiments must be simulated, irrespective of whether or not real-world observations of that type exist or not. The approach taken for the work presented here is somewhat simplistic: For data with existing real-life parallels (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 in the operational data stream used 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 T511NR 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.

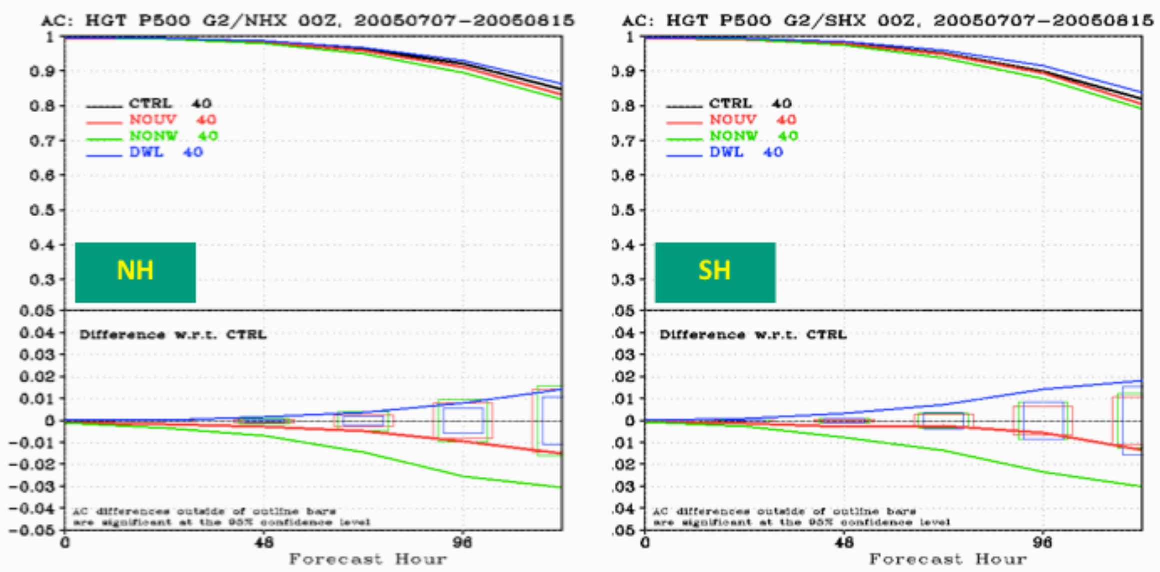

Figure 2: **Anomaly correlation coefficients in the NH (left) and SH (right) for the four experiments described in the text: CTLR (black), NOUV (red), NONW (green), and DWL (blue). Lower panel shows differences with respect to CTRL.**

Simulated satellite radiances were obtained by processing T511NR 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 T511NR were used, 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 the GWOS 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). Direct and coherent detection returns were simulated separately and a detailed model of the instrument error propagation onto the final error of the wind product was included.

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

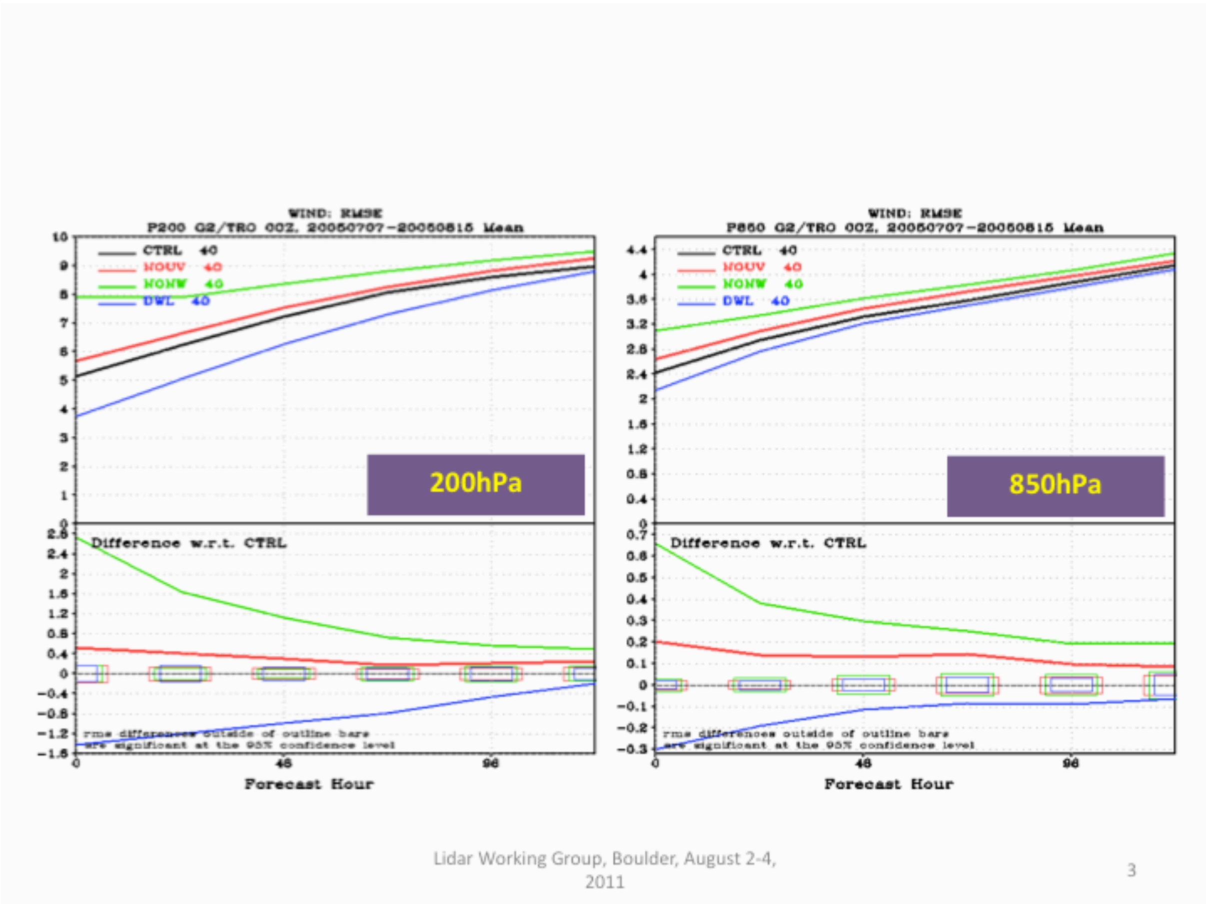

Figure 3: **Root Mean Square errors in the tropics at 200 hPa (left) and 850 HPa (right) for the four experiments described in the text: CTLR (black), NOUV (red), NONW (green), and DWL (blue). Lower panel shows differences with respect to CTRL.**

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. The results of these experiments were as expected: The skill of the OSSE system is slightly higher than that of its real-life sibling, but not excessively so (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.

In the final step, a set of three perturbation (assessment) 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 the simulated GWOS DWL 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.

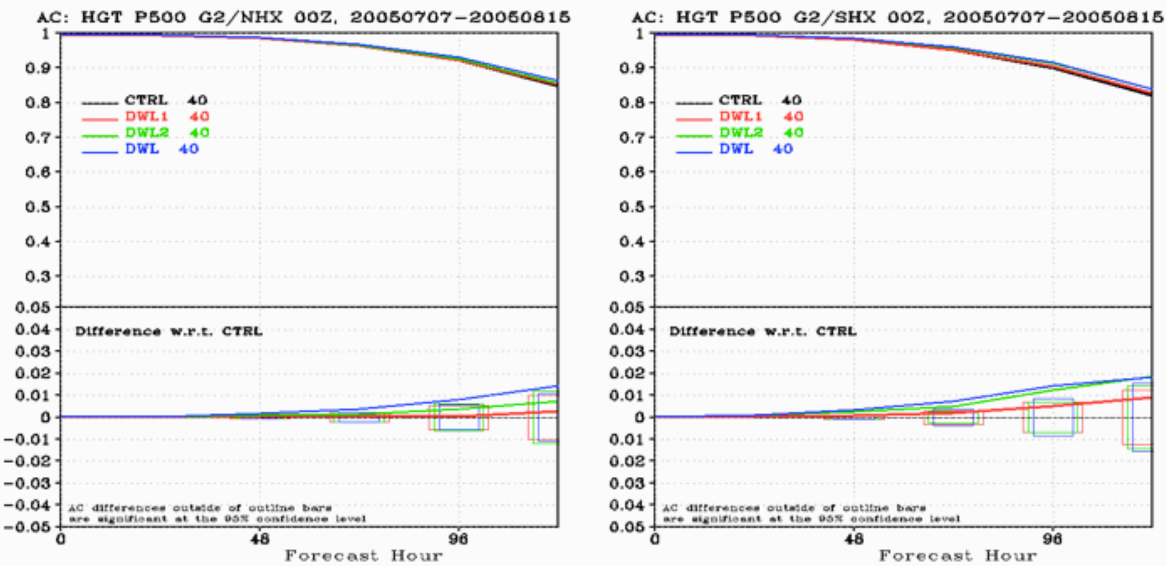

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Figure 4: **Anomaly correlation coefficients for 500 hPa geopotential heights in the NH (left) and SH (right) for the following four experiments described in the text: CTLR (black), DWL1 (red), DWL2 (green), and DWL (blue). Lower panel shows differences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

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.

As mentioned in the introduction, the GWOS configuration includes four separate telescopes in order to both increase the data coverage provide measurements of both horizontal wind components. The final set of experiments discussed in this paper is 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-hand 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 expected since even the four-telescope configuration provides only a relatively sparse set of wind measurements. However, the progression of impact from one experiment to the next is interesting. In both hemispheres, the impact of 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 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 two single-perspective instruments observing along parallel directions.

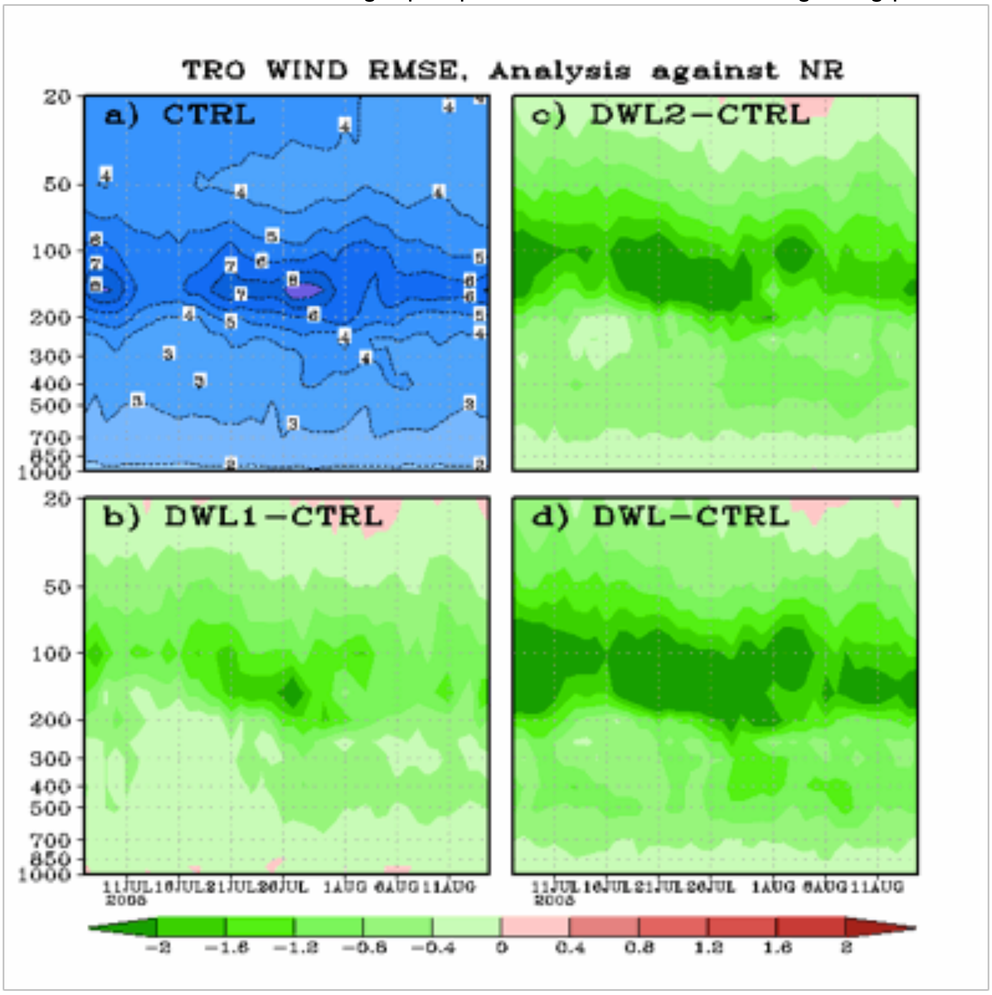

Figure 5. **Difference between tropical winds analysis RMS error as a function of time (x-axis) and height (y-axis) for the control run (upper left); difference w.r.t. control run of DWL1 (lower left), DWL2 (upper right) and DWL (lower right). Green means experiment performed better than control (closer to T511NR), red is worse than control.**

This is further illustrated in Figure 5, which shows RMS errors in tropical wind analyses as a function of time and height (upper left panel). The remaining three panels show the difference in tropical RMS wind errors between the performance of the control and the respective perturbation experiments (see caption). It is seen that the lidar winds lead to a dramatic improvement in the quality of the tropical wind analysis, especially in the tropopause region near 100 hPa. The impact is positive at all levels and at all times, but it is much more pronounced in the DWL2 and DWL experiments. There are no signs of saturation of impact, which supports the hypothesis that the existing Global Observing System is starved for wind measurements, especially in the tropics.

SUMMARY AND CONCLUSIONS

We have presented the Joint 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. The impact on analysis and forecast skill in the tropics is initially very strong and significant at all levels, but it tends to diminish rapidly through the forecast range due to the generally low predictability of these regions.

ACKNOWLEDGEMENTS

Financial support for this work was provided by NASA (R. Kakar) through ROSES (grant no. NNX08AQ44G). Computational resources for the impact experiments were made available by NOAA/NCEP. The T511NR was provided by Erik Andersson, ECMWF. Simulated GOES radiance data were provided by Tong Zhu, NOAA/NESDIS.

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