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LIDAR OBSERVATIONS VERSUS FORECAST OF WATER VAPOR TRANSPORT

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ABSTRACT

Water vapor advection is an important diagnostic parameter for initiation and sustenance of convective systems. This variable has traditionally been explored with balloon soundings or models, but lidar provides a unique opportunity to continuously resolve spatial and temporal evolution of water vapor transport with relatively high resolution. In this study we utilize co-located Doppler wind lidars and water vapor lidars (DIAL and Raman) at multiple sites to investigate water vapor advection. A case of nocturnal convection in the Great Plains is analyzed with these observations and compared to the North American Mesoscale Forecast System (NAM) operational forecast model.

1. INTRODUCTION

Mesoscale convective systems (MCSs) are large, intense convective systems that bring substantial rainfall and potentially damaging winds or hail. MCSs are particularly impactful in the Great Plains region of the United States, where warm-season MCSs can form and persist overnight. Forecasting these events and related phenomena such as low-level jets (LLJs) and bore waves is challenging. In 2015 a large field campaign was executed to address these issues, called Plains Elevated Convection at Night (PECAN) [1].

PECAN had several fixed and mobile sites equipped with in situ and remote sensing instrumentation. Three of these sites, spread across Oklahoma and Kansas with significant latitudinal and longitudinal separation, featured both a Doppler wind lidar and a water vapor lidar. This setup is conducive to observing the mesoscale phenomena of interest, especially water vapor transport caused by LLJs. LLJs are strong wind events within the lowest 2 km of the atmosphere and are known to advect moisture and warm temperatures northward, critical for initiating or fueling convection [2]. Because these events are often poorly forecasted, this study will address a case of a LLJ feeding into an MCS through the lens of lidar observations to understand details of the event as well as compare the observations to an operational forecast of the domain. The chosen forecast model is the North American Mesoscale Forecast System (NAM) model, run and archived by NCEP.

2. METHODOLOGY

2.1 Lidar systems

The data shown here comes from four lidar systems; two sites each featuring wind and water vapor systems. The northern site, closer to the MCS of interest, is denoted as “FP3” and featured a water vapor DIAL developed by NCAR [3]. The southern site, “FP1”, featured the ARM SGP Raman lidar for water vapor profiling [4]. Nocturnal measurements from these lidars compare very well to balloon soundings, as shown in Figure 1. The lidar sites are marked in Figure 2.

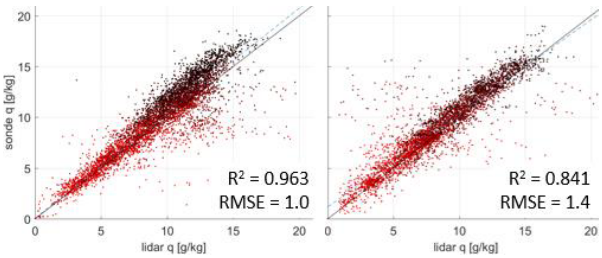

Figure 1. Comparison of water vapor mixing ratio (g/kg) from sonde and lidar at FP1 (left) and FP3 (right), with dashed line of best fit and solid 1-to-1 line. Color indicates measurement height, fading black to red from 0 km to 3 km.

The Doppler lidars are both commercial heterodyne systems operating at 1540 nm. The lidar at FP3, a Leosphere WINDCUBE®70, operated with the common four-azimuth Doppler beam swinging (DBS) pattern to allow wind profile retrieval. FP1’s Halo Stream Line Pro performed conical scans with beams at 8 azimuths. Wind profiles from these Doppler systems compared very well with balloon soundings (figures not shown).

2.2 Water vapor advection calculation

Water vapor advection is calculated as the product of the wind speed and the water vapor mixing ratio. These fields are retrieved by the lidars at different spatial and temporal resolutions, so the higher-resolution profile at a given site is interpolated to the lower resolution. The same approach is used in comparing the observed advection fields to the relatively coarse NAM model output.

2.3 Case of interest: 11 July 2015

On 11 July 2015, the PECAN experiment focused on an MCS on the Kansas-Nebraska border (overlapping with FP4 in Figure 2). MCSs also developed in north-central Nebraska and northern Missouri. The main system of interest began shortly before sunset and grew overnight into a multi-celled MCS, slowly propagating eastward and dying out at sunrise. It produced over 35mm of rain along much of its track. NAM predicted the convection initiation but did not capture the correct motion, intensification, and rainfall of this event, nor did it accurately develop the two nearby MCSs.

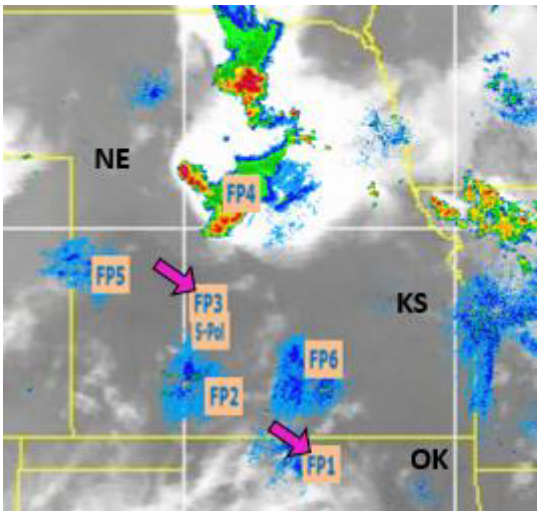

Figure 2. Radar mosaic at 0615 UTC. Ground sites, including FP1 and FP3, are identified. Shading is GOES-13 near-IR.

The 12km-resolution NAM model run used in this study is the 0000 UTC run from 10 July 2015, so convective events of interest are happening at forecast hours 20-36.

3. RESULTS

The lidars were able to capture features of the LLJ and boundary layer water vapor in great detail for this study. The product water vapor advection profiles are shown in the top row of Figure 3. NAM shows qualitatively similar evolution of the water vapor advection profile (Figure 3, middle row) but critical shortcomings are revealed in the forecast error plots (Figure 3, bottom row). Plots of the separate lidar fields of winds and water vapor also aided in analysis (not shown here).

Wind profiles from the lidars detected a southerly direction for the strong LLJ, thus the latitudinal separation of FP1 and FP3 gives spatial context to the LLJ's along-track transport. FP1, the southern site, had a very moist afternoon boundary layer that dried out overnight. FP3 experienced the opposite; a drier afternoon boundary layer became moister overnight, eluding to northward transport of water vapor by the LLJ. Water vapor advection shown in Figure 3 depicts fairly constant transport throughout the night at FP1, as the site grew drier and the LLJ simultaneously strengthened.

The maximum in water vapor advection observed on this night was in the core of the LLJ around 0600 UTC at FP3. This timing corresponds with the appearance and rapid intensification of a new cell in the MCS along the Kansas-Nebraska border, highlighting the importance of water vapor advection to MCS evolution. This same water vapor advection feature was the largest instance of underprediction by NAM. Investigation of forecast errors in the separated wind and water vapor fields shows the NAM underpredicting the FP3 peak LLJ wind speed by 6 m/s, with less consistent or large bias in the FP3 water vapor profile. While this failure of NAM is critical towards MCS development, other model dynamics and parameterizations are presumably also important to NAM's misplaced location and development of the MCSs in this time frame.

4. SUMMARY

Co-located lidar observations of winds and water vapor during PECAN provided a rare opportunity to investigate water vapor advection, an important parameter for convective initiation and intensification. A case study of 11 July 2015 was presented here. The lidar profiles revealed a maximum in water vapor advection at the northern site, closest to the MCS of interest, at the same time that a new cell developed and intensified. The NAM model severely underpredicted this advection feature and failed to capture the rainfall location, timing, and amount over the course of the night within the PECAN region.

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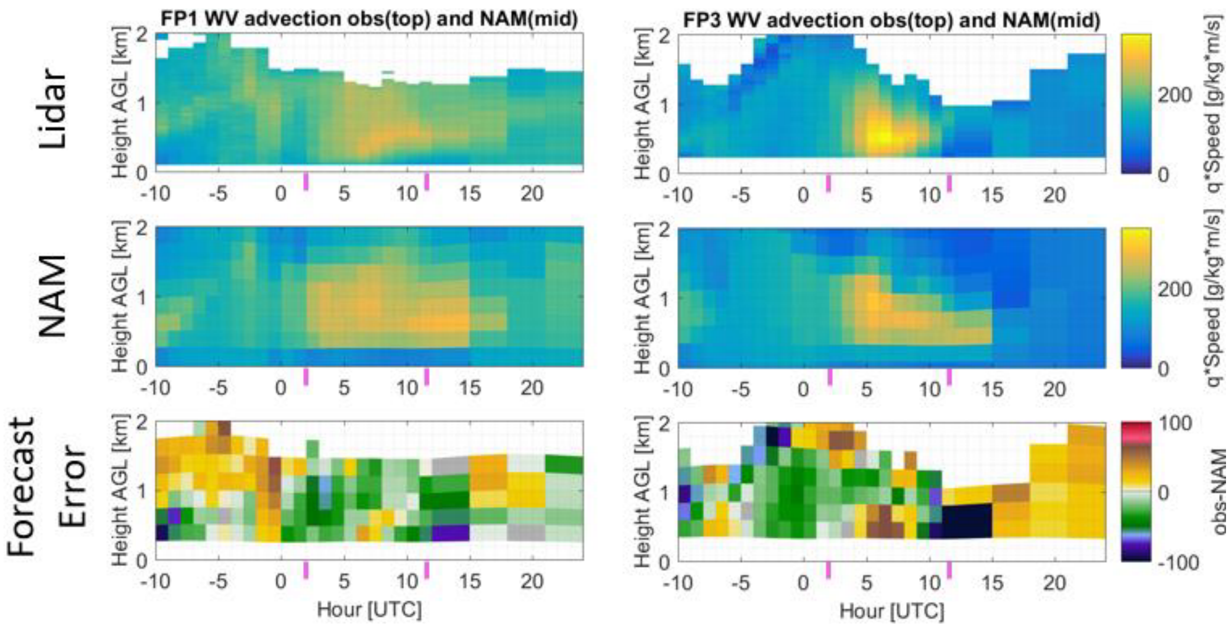

Figure 3. Water vapor (*WV*) mixing ratio (*q*) and advection profile timeseries from observations and NAM, along with forecast error (obs-NAM). Left column is at site FP1, right column is FP3. 0 on the x-axis is 0000 UTC, 11 July. Magenta lines indicate sunset (~0200 UTC) and sunrise (~11 UTC).