P1.2 INTEGRATED REAL-TIME AIRBORNE DOPPLER LIDAR WIND AND AEROSOL MEASUREMENTS WITH OPERATIONAL MESOSCALE AND DISPERSION MODELS

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1. Introduction

With the intensifying interest in the detection and prediction of pollutants and airborne contaminates (NBC agents, for instance), the need for high resolution (space and time) wind/aerosol observations and the forecast/transport models that can correctly use those data for nowcasting and short term prediction also grows. Besides rapid-response forecast models, superior knowledge of the state of the atmosphere, particularly the wind and aerosol fields, can also be used in dispersion models as well as in military planning through the use of weather impact decision aids (WIDAs). Urban and complex terrain situations are most challenging to these tasks and have been the target of recent field experiments such as CASES-99 (Newsom and Banta (2003) and JOINT URBAN 2003 (Wang et al., 2004; Yee et al., 2004). The latter included the deployment of ground-based, wind-measuring coherent Doppler lidars. While numerical models continue to improve in terms of spatial resolution and computational efficiency, direct measures of winds are still needed for making good decisions in real time.

Traditionally, direct observations of winds can be obtained with tower or tethered balloon mounted anemometers, drift balloons, rawinsondes, dropsondes, SODARs, and, under special conditions, ground based radars. These methods of wind measurement suffer from one of three limitations: spatial representativeness, rapid deployment and adaptive mobility. The airborne Doppler wind lidar (DWL) can provide wind and aerosol profiles with high space and time resolution (coverage dependent on the aircraft performance), flown to specific targets of interest with dwell options and, unlike the radars, need only aerosols (or molecules in some instances) to provide useful signals.

Airborne Doppler lidar using coherent detection is now mature enough to be called operational. Simpson Weather Associated (SWA) has previously been funded by the Office of Naval Research and the Integrated Program Office (IPO) of NPOESS (National Polar-orbiting Operational Environmental Satellite System) to use a 2 micron coherent Doppler lidar mounted in a Navy Twin Otter aircraft to conduct a variety of investigations. SWA has developed software, scanning strategies and data processing algorithms that have resulted in high accuracy (< .05 m/s) in the wind observations and high resolution of aerosol features (< 5 meters in some instances).

Table 1 summarizes the technical details of the Twin Otter DWL (or TODWL). A defining capability of the TODWL is its ability to profile above and below the flight level. With its side door mounted, two axis scanner, the beam can be adaptively (in flight) directed in a variety of scan patterns including conical, nadir stares and flight level stares.

The objectives of a series of flights in 2002 and 2003 included:

- Validation of numerical model predictions of flow over complex terrain (Greco and Emmitt, 2005; Emmitt et al. 2003)
- Investigation of the interactions of aerosols and winds within the planetary boundary layer (Emmitt and O'Handley, 2003)

Comparisons with ground based microwave sounders illustrate excellent agreement given the differences in averaging time (Figure 1).

As mentioned above, the TODWL system has also been used in validation studies of numerical model predictions of flow over complex terrain. Specifically, the TODWL

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collected more than 1000 profiles of the winds and aerosols during a 4 hour flight in the area near Monterey, California.

The MM5 at the Naval Postgraduate School was run for the same time period at 4 km resolution. Of particular interest were the comparisons of the DWL and MM5 winds just above the coastal ocean surface (Figure 2) and at the intersections of valleys in the surrounding area.

The airborne wind and aerosol data that would be obtained and processed by TODWL could be fed into and utilized by both forecast models and transport and dispersion models such as RIMPUFF and SCIPUFF in real-time. A recent effort by Warner et al., (2003) describes the assimilation of lidar and radar winds (but only used radar winds) into the SCIPUFF model.

2. Research and Development

Under funding from the Army Research Office (ARO), SWA has demonstrated the feasibility of packaging and extending (new software) post-flight data processing software to where it can be used as an onboard autonomous system for processing airborne Doppler Wind Lidar (DWL) data, making on-board comparisons with model data and, ultimately, mission operation decision-making. The general architecture for the onboard autonomous airborne DWL data processing, model analyses/forecast verification, adaptive targeting system as described in the component diagram (Figure 3) was developed. A testbed was constructed to evaluate the performance of a complete end-to-end data processing. Using this testbed, the Airborne Doppler Lidar Analyses and Adaptive Targeting System (ADLAATS) was exercised to demonstrate:

- The ingestion of data from the existing TODWL DAS (data acquisition system) and processing it in real-time for line-of-sight (LOS) winds, aerosol backscatter and wind variance, and

- The comparison of LOS wind observations with expected LOS wind components obtained by applying a forward model to the up-linked analyses of the moment and the most recent numerical model predictions.

Through a series of tests, we have benchmarked the flow of information from the laser to the data assimilating models in terms of processing time and the timely utility for real-time systems. The ADLAATS testbed was populated with existing code and new code such as a simple forward model for reading and processing model data. The issue of onboard execution of a forward model operating on the gridded fields of a mesoscale model output was also addressed. A major technology question to be resolved was how much of the available model output fields must be uploaded to the aircraft and how often need it be refreshed. The bandwidth of the up/down link will determine the volume of data that can be accommodated. Computational speeds are displayed in Table 2.

In the performed tests, we established performance benchmarks and evaluated the functionality of the different segments of ADLAATS. This included but was not limited to:

- Demonstrating that ADLAATS and the ADLAATS forward model (for the numerical model output) can compute LOS and horizontal winds for evaluation and comparison.

- Demonstrating how the Data Product Evaluation Model (DPEM) would communicate with ADLAATS to adjust scanner inputs and/or aircraft flight modifications in order to best validate DWL and model products.

- Demonstrating how ADLAATS would recommend on-board flight modification and communicates to the pilot for mission adjustments.

Using model outputs from the Naval Post Graduate School (NPS) MM5 model runs, SWA demonstrated ADLAATS and it’s response to DPEM logic dealing with successful evaluations and failure LOS evaluations. Figure 4 shows the distribution of differences between the model forecast or expected value and the TODWL measurements for all samples on one TODWL mission.

Summary and Future Research

Ongoing work by SWA has demonstrated the collection, processing and transmitting of real-time wind and aerosol profiles obtained with an airborne Doppler lidar and the feasibility of making on-board comparisons with numerical and dispersion model data and, ultimately, mission operation decisions. A complete coding of an end-to-end ADLAATS software package is underway with a focus on improving the efficiency and the time it takes to process, upload and download the data onboard. Field tests and data utility demonstrations will be planned to validate the general concept of ADLAATS and to identify those areas that need to be optimized.

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Wavelength (microns)	2.05 (eyesafe)
Energy per pulse (mJ)	2-3
Pulse repetition frequency (Hz)	500
Scanner	2 axis (+- 120; +- 30)
Range resolution (meters)	50-100
LOS measurement accuracy (m/s)	< .05 per single shot w/ground calibration
Wind component accuracy (m/s)	u,v,w < .1 m/s nominal using a 30 degree VAD and LADSA
Aerosol backscatter threshold sensitivity	Range dependent: ~ 10 -08 m sr-1 at 10km
Nominal range to insensitivity (km)	Aerosol dependent: nominal 15-20 km in PBL and 2-5 km above PBL

Table 1: Description of TODWL

OPERATION	EXECUTION TIME	FILE SIZE
Acquire raw data (500MHz)	**5 minutes (15 -20 profiles)**	**20,000kB**
LADSA (once per hour)	**90 seconds**	**N/A**
LOS processing (500 shots/LOS/second) w/ threading	**23 seconds (for 5 minute raw data file)**	**170 kB**
VAD processing (sine fit; multi-Var)	**35 seconds; 80 seconds (15-20 profiles)**	**140 kB**
MM5 wind field (uploaded to aircraft) (two time steps for interpolation)	**< 10 seconds for forward model and data comparisons**	**420 kB**

Table 2: Code timing and file size. * Timing tests were run on a Dell 5100, Pentium 4 CPU w/ 512MB RAM. File size does not reflect any data compression.

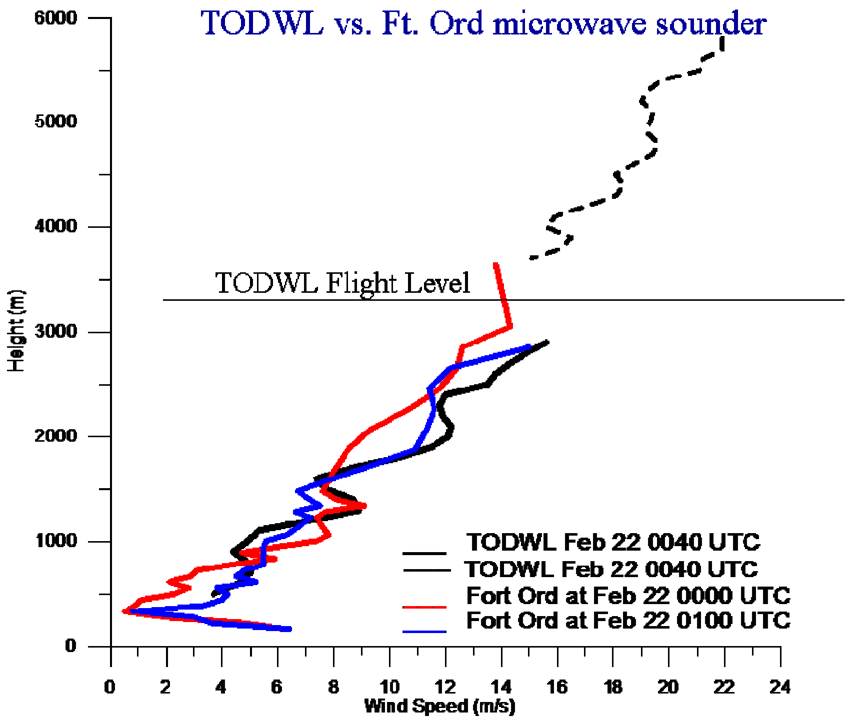

Figure 1 Comparison of TODWL sounding (black lines) with two soundings from Ft. Ord microwave sounder

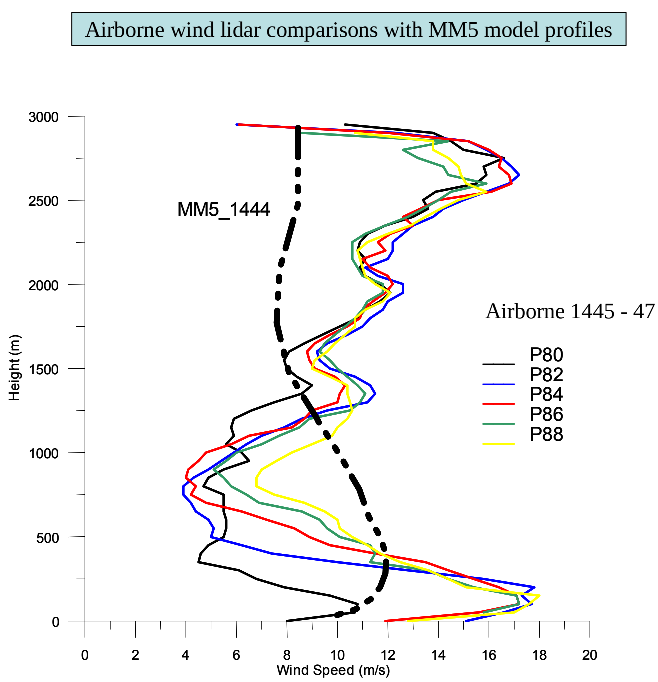

Figure 2 Comparison of 5 TODWL soundings taken ~ 1 km apart with the nearest MM5 data

Doppler Lidar Analysis and Adaptive Targeting System (DLAATS)

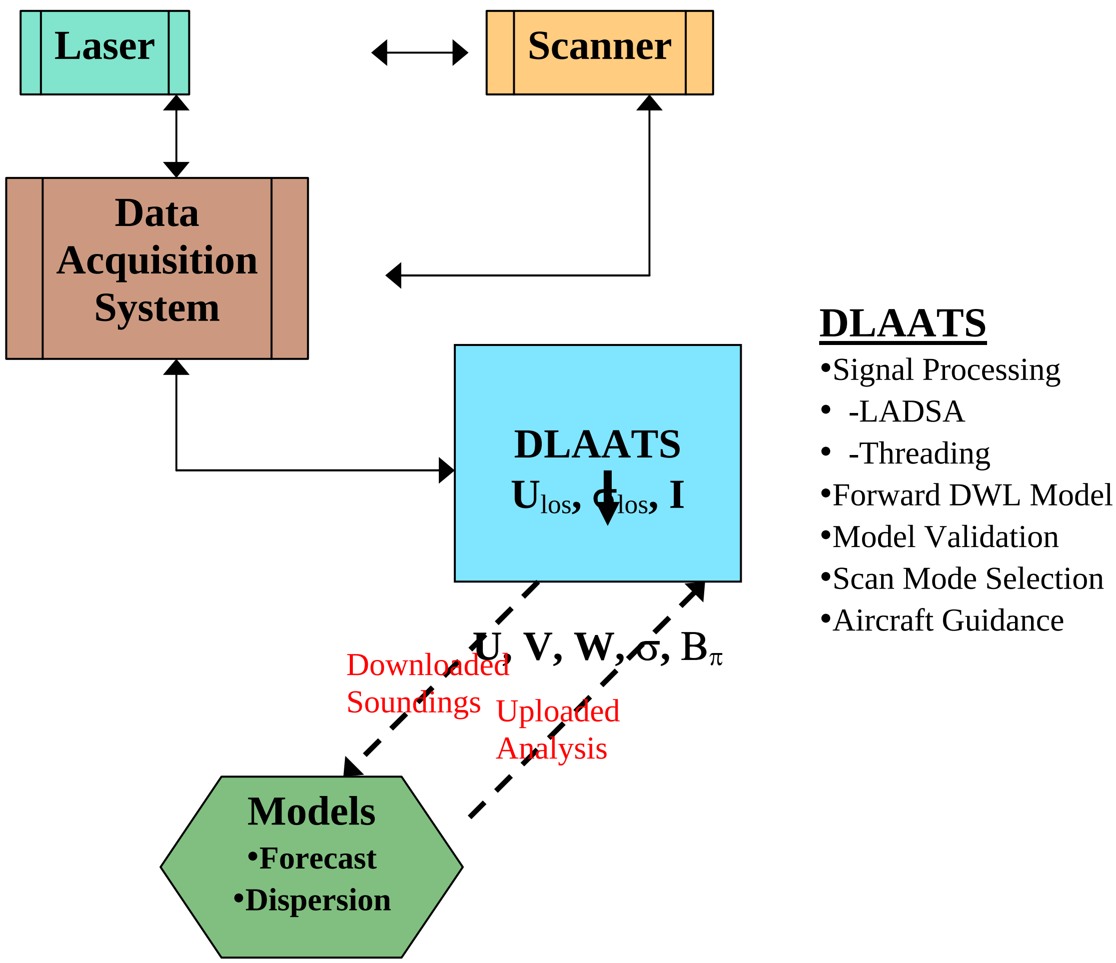

Figure 3: Component diagram of interfaces between ADLAATS, the wind lidar and the information provided by models or observations

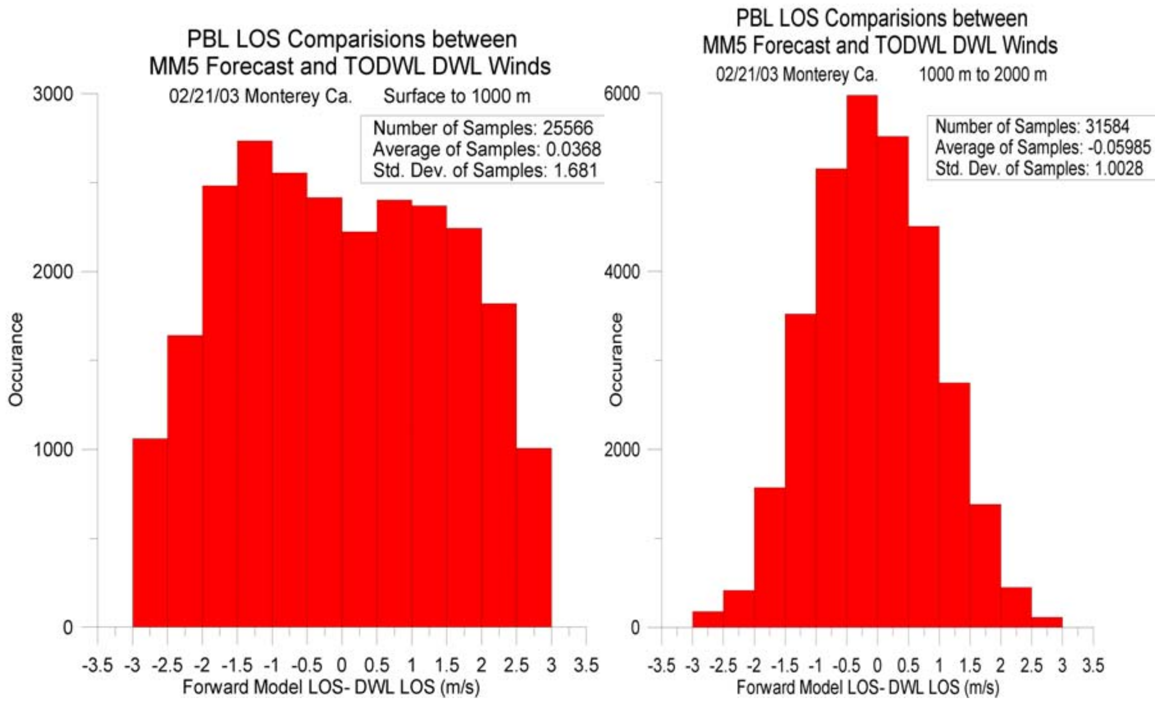

Figure 4: Distribution of differences between the model expected value and the TODWL measured value for all samples between 1000 and 2000 meters MSL (on left); same for the layer between the surface and 1000 meters (on right).