6.2 MERITS OF A SPACE-BASED HYBRID DOPPLER WIND LIDAR

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1. Introduction

Data requirements from NASA/NOAA and WMO have been developed to help assure significant impacts on weather forecasting skill and utility from current and future direct wind measurements. This goal will not be achieved by relying solely on either of the coherent or direct detection lidar technologies. In addition, given the current state of the direct and coherent detection lidar technologies, a single detection approach results in very large (both physical & cost wise) instruments that would require significant new technology development.

The hybrid Doppler Wind Lidar (DWL) approach is based upon a notional concept (Emmitt, 1995; Emmitt, 2000) that combined the best features of coherent detection and non-coherent (aka direct detection) to achieve a space-based wind observing capability sooner and possibly at less cost than approaches that relied on just a single technology. While sharing the costs of launch, platform, data system, power management, thermal controls, science team, and mission operations, the hybrid DWL would permit each detection system to be optimized for that portion of the tropospheric wind profiling task for which it is best suited. Furthermore, by adopting the hybrid approach to DWL operations, neither technology would be driven much beyond the current state of the art.

One hybrid DWL concept would use a modest sized coherent system to make measurements in the lower troposphere and in cloudy areas (usually indicating dynamically active areas). While the coherent system coverage may favor dynamically active regions of the atmosphere, there are convincing arguments for also making measurements in the mid and upper portions of the cloud free troposphere.

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In these regions, the non-coherent DWL offers a technique that can use Rayleigh backscatter when the aerosol concentrations are below the coherent detection thresholds. We speak of coherent detection as having a coverage problem with innate good velocity accuracy, and non-coherent detection as having an accuracy problem with innate good coverage. The thought of advancing either technology to the point of eliminating its respective problem would entail laser pulse energies and rates, and telescope diameters that are not feasible for space missions in the foreseeable future (Emmitt, 2000). Large average power lasers for either technique would involve prohibitive cost, mass, power, heat removal, and optics lifetime. Large telescope diameters for non-coherent DWLs are discussed, but the science requirements require step-stare scanning and very good pointing knowledge. This leads to the suggestion of using smaller, more feasible versions of both coherent and non-coherent systems to deliver high-accuracy, high-resolution measurements by the coherent DWL when aerosol backscatter is sufficient, and to deliver complementary non-coherent DWL winds from all regions. This division of responsibility should allow each system to be optimally designed to succeed at its role. A natural cross-calibration of winds will occur whenever the coherent lidar is able to make measurements. The two wind lidars would thus provide some measure of redundancy.

2. Direct Detection Alone vs Hybrid

The following discussion assumes a common set of mission parameters presented in Table 1. While the NPOESS (National Polar Orbiting Environmental Satellite System) orbit is currently set (and limited to) 833km, the additional range required of the DWLs would further increase the size of the lidar systems by ~5X. Thus, an orbit of 400km was chosen as part of an active argument for a lower orbit altitude.

In the following table 2, three versions of a "direct detection only" system based upon a Global Tropospheric Wind Sounder (GTWS) system design are described. The IPO (Integrated Program Office for the NPOESS) baseline resulted from a set of engineering reviews conducted at NASA/GSFC which were then used (with some updating) by the IPO in its evaluation of the hybrid approach. The reason for the two hybrid options is the recognition that the power requirements for the system area primary driver on platform costs. The IPO2 option assumes that within the direct detection technology, a factor of two improvement in total throughput efficiency can be found over that currently demonstrated.

Special note should be made of the ~ 10X reduction in the power requirements for the hybrid vs. the direct alone option. This resource requirement reduction along with the reduced telescope size, would have a major impact on mission complexity and costs.

3. Coherent Detection Alone vs. Hybrid

In the case of the "coherent only" system, detailed designs of potential space-based systems and the heritage of operational ground and airborne systems offer a fairly stable set of design parameters with a low probability of finding factors of 2 or greater in a near-future system. These designs are presented in Figure 3. Again, as was the case for the direct detection technology, a factor of 10 reduction in power requirements must be considered significant. In addition, the smaller telescope size for the hybrid has significant implications for system alignment.

4. Hybrid DWL

In Table 4, two hybrid operational class DWLs are defined. One uses the larger direct detection subsystem that meets the data requirements and the other uses a smaller system that assumes at least a factor of two improvement in throughput/detection efficiency over that demonstrated to date within the NASA laboratories.

As has been the case for the individual technology DWL concepts, there is a funded effort to evaluate the potential data impacts of the hybrid DWL on operational weather forecasting. This is done using Observing System Simulation Experiments (OSSEs) where simulated DWL winds must compete with all other sources of wind data used by today's operational and research global forecast models. OSSEs are on-going at both NOAA/NCEP and at NASA/GSFC. A Doppler Lidar Simulation Model (DLSM) is used with a high resolution global model 30-90 day run to provide truth for simulating the observations (effects of clouds, wind variability, aerosol distributions, etc. included) which are then used with a different global forecasting model to assess impacts. The following "performance profiles" were developed along with the DLSM to summarize the vertical coverage of a specific DWL concept using specific assumptions of aerosol concentrations and realistic atmospheric situations as provided by the "nature runs" mentioned above.

In using the "performance profiles" it should be understood that the horizontal axis expresses the percentage of all DWL lidar sampling attempts within the specified simulation time period (usually 24 hours) that meet the criteria of accuracy noted in the color key on the right. Most of the information need to interpret the charts is provided within the chart itself. It is important to note that the accuracies are those realized after the Line-of-Sight uncertainties are projected onto the horizontal plane and are thus larger than those reported as unprojected LOS errors. The black areas to the right of the chart represent the percentage of time that the lidar can not provide any useful (errors < 3 m/s) information due to obscuration by clouds or insufficient signal to obtain a useful observation.

In Figure 1, a performance profile for the Hybrid DWL described in Table 4 is shown for the case where the entire globe is covered by the "background" mode of aerosol distribution. The background mode has been defined by both airborne field studies and models and is meant to represent the most demanding (lowest concentrations) conditions in which an aerosol DWL system must perform to meet the GTWS data requirements. In this case the direct molecular subsystem provides most of the useful (RMSE < 3 m/s) wind observations in the cloud free regions above the boundary layer.

In the case (Figure 2) where the vertical distribution of aerosols is enhanced (by convection, dust layers, aerosol pollution, etc.) the coherent system provides very accurate (~1 m/s or better) observations throughout most of the troposphere. These enhanced conditions are expected frequently over much of the continental northern hemisphere in the summer.

Given the normal and prudent approach to deploying new technologies in space, it is likely that an airborne version of the hybrid DWL will be built first. Both the direct and coherent sub-systems will produce exceptional data.

Example performance plots for airborne hybrids are displayed in Figures 3-5.

5. Synergisms

There is a temptation to look for technology synergy between coherent and non-coherent DWLs. This is due to the common overemphasis on technology. The primary synergy of these two techniques/technologies is the science performance synergy mentioned earlier(Figure 1). The secondary synergy is the space wind mission synergy (e.g., rocket, platform, heat removal, pointing knowledge, data downlink, and science team). Technology synergy follows from these two, and may include a common telescope or scanner in the future. Technology synergy is not required to claim excellent synergy in this application.

Several of the data and mission synergisms realized by the hybrid DWL concept are:

- The hybrid approach will provide full tropospheric wind observations **sooner**, with much of the accuracy, resolution and coverage needed by tomorrow's global and regional models
- The molecular DWL sub-system would, in its first mission, provide useful wind observations in cloud free regions of the mid/upper troposphere and lower stratosphere
- The coherent DWL sub-system would immediately meet the science and operational requirements throughout the troposphere in regions of high aerosol backscatter (dust layers, clouds, PBL aerosols)
- The molecular system may provide good first guesses in the coherent system's weak signal regime, enabling the coherent system to provide a more accurate wind observation than either system alone could make.
- The coherent system could be optimized explicitly for resolving the ageostrophic features (moisture jets, Tropical circulations) of the lower troposphere, while the molecular system could be optimized to produce fewer, but still accurate, observations of the larger divergent features of the mid and upper troposphere
- The more dynamically interesting regions of the troposphere usually involve clouds. The coherent system is best suited to sampling through and below clouds. The molecular system, which is compromised by clouds, would provide the winds above and around the generally cloudy areas

6. Summary

Based upon ongoing evaluation of a hybrid DWL for global tropospheric (and lower stratospheric) wind sounder, the potential cost and mission risk reductions are reason to use the hybrid technology as the base-line approach. In summary:

- The Hybrid DWL approach is on the current NASA/NOAA DWL technology roadmap for global winds

- The hybrid approach will provide full tropospheric 2-D wind observations sooner than single detection technology approaches, with much of the accuracy, resolution and coverage needed by tomorrow's global and regional models

- The IPO of the NPOESS has funded a team to develop the design of a hybrid DWL airborne testbed and cal/val instrument (NASA, NOAA and Industry)

- The IPO has also funded OSSEs to refine several DWL concept technology requirements

7. Acknowledgements

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8. References

Emmitt, G. D. ,2000: Hybrid technology Doppler wind lidar: assessment of simulated data products for a space-based system concept, SPIE Lidar Remote Sensing for Industry and Environment Monitoring, Sendai, Japan, October.

Emmitt, G. D. , 1995: Initial concept for a wind observing satellite- hybrid (WOS/H). Working Group for Space-based Lidar Winds, Clearwater, FL, January 1995.

Parameter	**IPO Study Missions**
Orbit Height	400 km
Orbit Inclination	98 degrees
Nadir viewing angle	45 degrees
Duty cycle	100%

Table 1. General mission parameters for IPO Hybrid feasibility study

Instrument Parameters	**IPO Baseline**	**IPO1 Hybrid**	**IPO2 Hybrid**
Wavelength (nm)	355	Same	Same
Pulse Energy (Joules)	1	0.2	0.2
Pulse Duration (sec)	20E-09	Same	Same
PRF (Hz)	125	60	30
Laser Wallplug Efficiency (factor)	0.016	Same	Same
Shot Integration (Number)	633	300	600
Azimuths in Sample Sequence (number of scan positions)	8	8	4
Energy per LOS Data Product (Joules)	635	60	60
Average Laser Power (Watts)	7812	750	375
Telescope Area (m^2)	1.23	0.78	0.5
Optical Transmission 2-way (factor)	0.034	Same	Same
Detector Quantum Efficiency (factor)	0.80	Same	Same
Data Rate (bits/hour)	0.88E+09	0.44E+09	0.44E+09
Mass of Instrument (kg)	TBD	TBD	TBD?
Total Average Power of Instrument (including scanner (watts)	8112	1050	675
Size (m)	3 x 1.5 x 1.5		

Table 2. IPO Baseline Direct and Hybrid Direct Detection Subsystem Parameters

Instrument Parameters	**IPO Baseline**	**IPO Hybrid**
Wavelength (nm)	2054	Same
Pulse Energy (Joules)	8	0.5
Pulse Duration (sec)	1.80.0E-09	Same
Pulse Repetition Frequency (prf) (Hz)	12	Same
Laser Wallplug Efficiency (factor)	0.02	Same
Shot Integration (Number)	60	Same
Azimuths in Sample Sequence (number of scan positions)	8	Same
Energy per LOS Data Product (Joules)	480	30
Average Laser Power (Watts)	4800	300
Telescope Area (m^2)	0.45	0.2
Optical Transmission 2-way (factor)	0.50	Same
Detector Quantum Efficiency (factor)	0.80	Same
Mixing Efficiency (factor)	0.40	Same
Data Rate (bits/hour)	26.2E+09	Same
Mass of Instrument (kg)	TBD	TBD
Total Instrument (including scanner) Average Power (watts)	5251	600

Table 3. IPO Coherent Detection Subsystem Parameters

Instrument Parameters **For** **Combined IPO Hybrid**	**IPO1 H(DD,CD)***	**IPO2 H(DD,CD)**
Average Laser Power (Watts)	750+300=1050	375+300=675
Effective Telescope Area (m^2)	0.78 0.2	0.5 0.2
Data Rate (bits/hour)	26 E09	26 E09
Mass of Instrument (kg)	TBD	TBD
Total Average Instrument Power (Watts)	1050+600=1650	675+600=1275

* DD is Direct Detection, CD is Coherent Detection

Table 4. Parameters for combined IPO Hybrid DWL

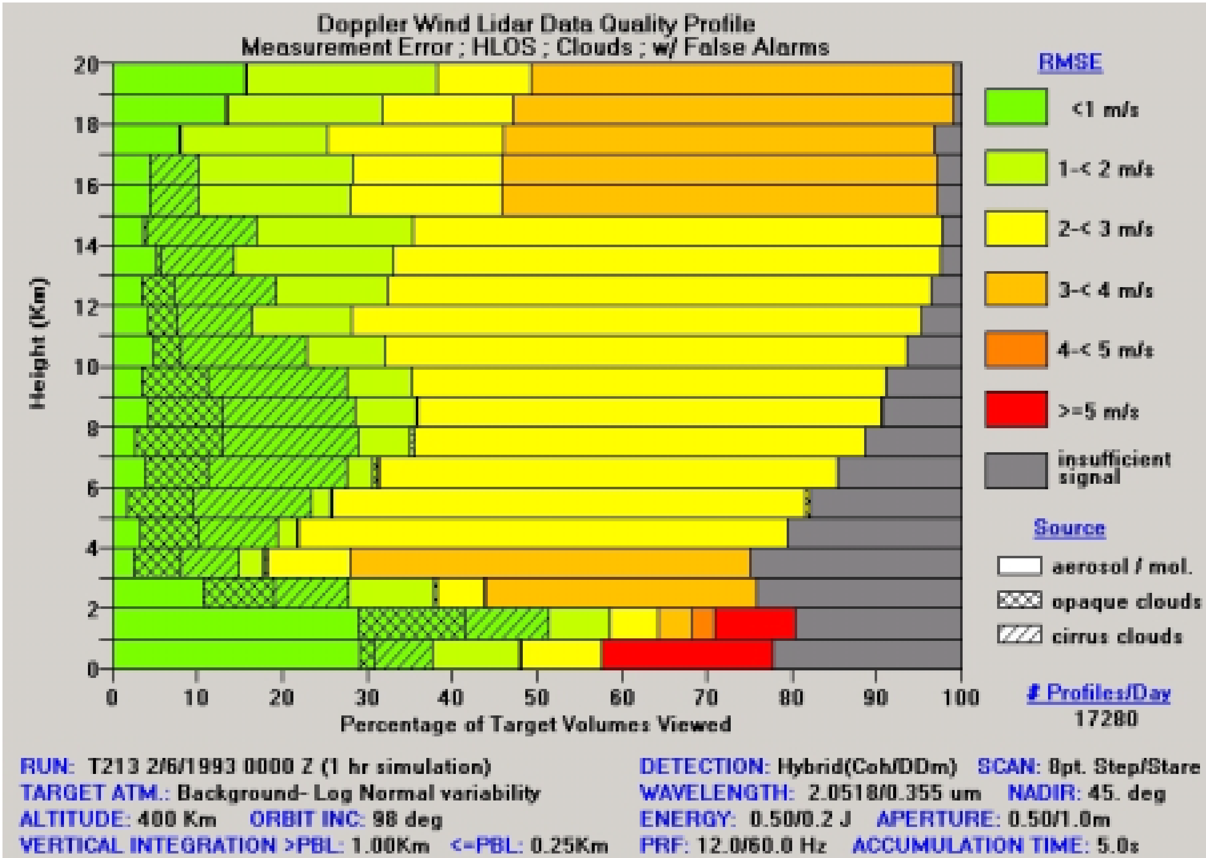

Figure 1. Performance profile for the hybrid DWL that would meet the NASA/NOAA global wind observation requirements in regions where the aerosols are concentrated in the lower troposphere (background mode).

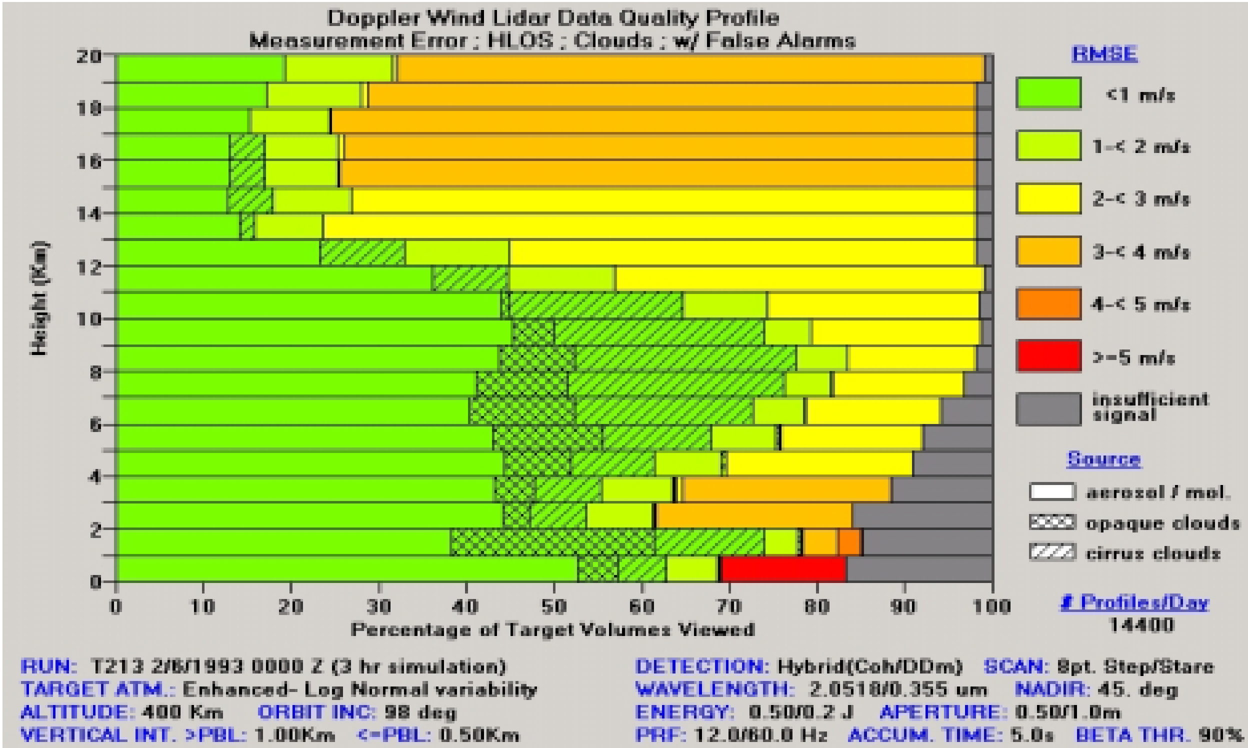

Figure 2. Performance profile for the same system used in Figure 1, except that the aerosol distribution was that expected for regions of the globe where there is significant vertical pumping of lower tropospheric aerosols (enhanced mode)

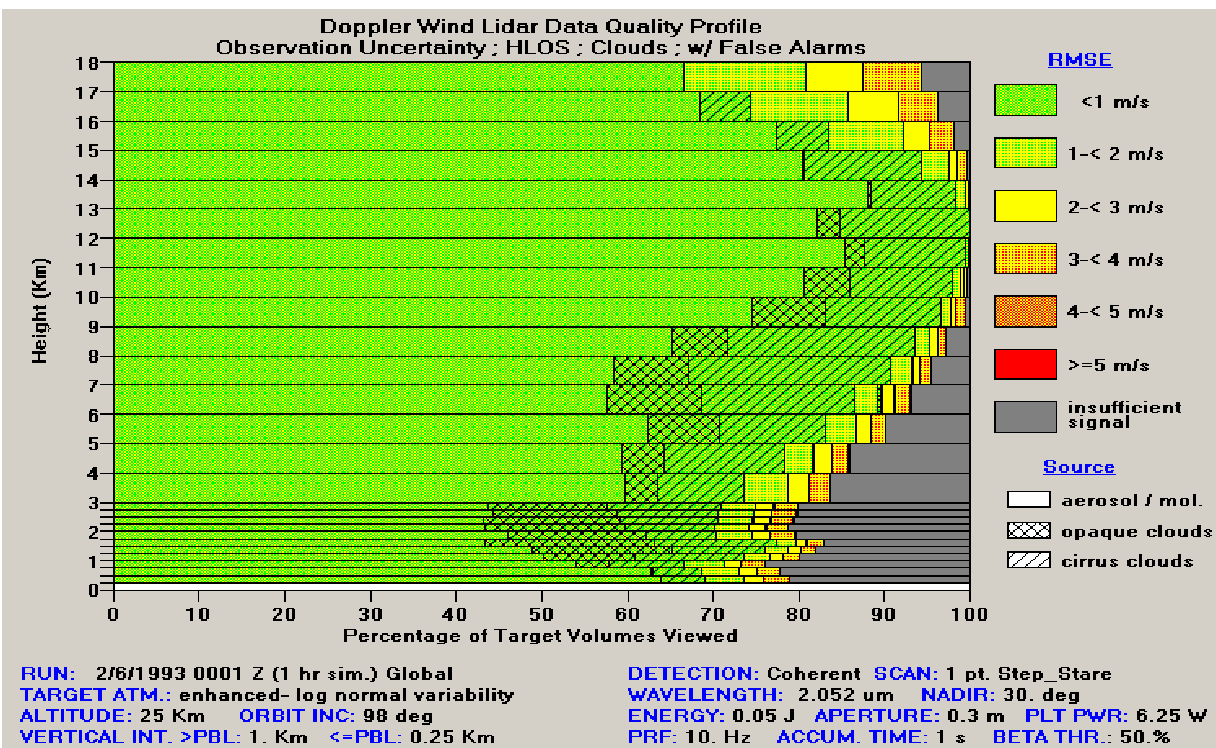

Figure 3. Performance plot of an airborne Hybrid/A coherent detection subsystem (Enhanced aerosol regime)

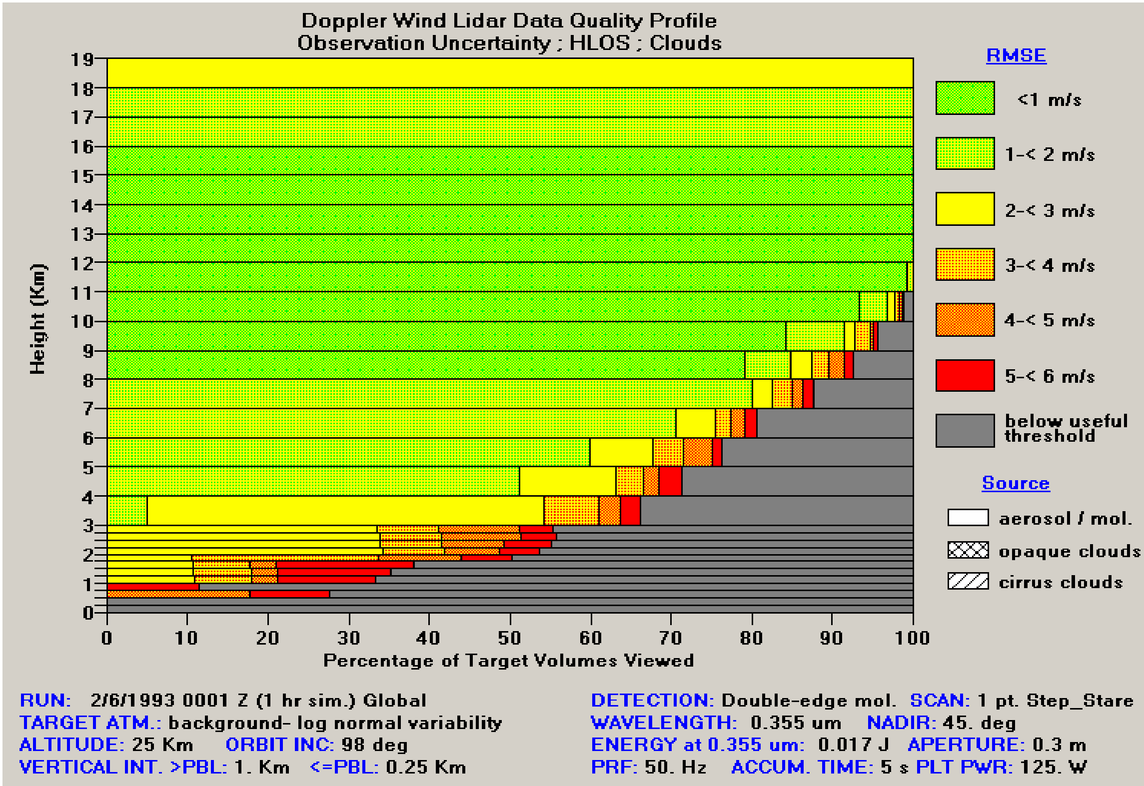

Figure 4. Performance plot of an airborne Hybrid/A direct detection subsystem

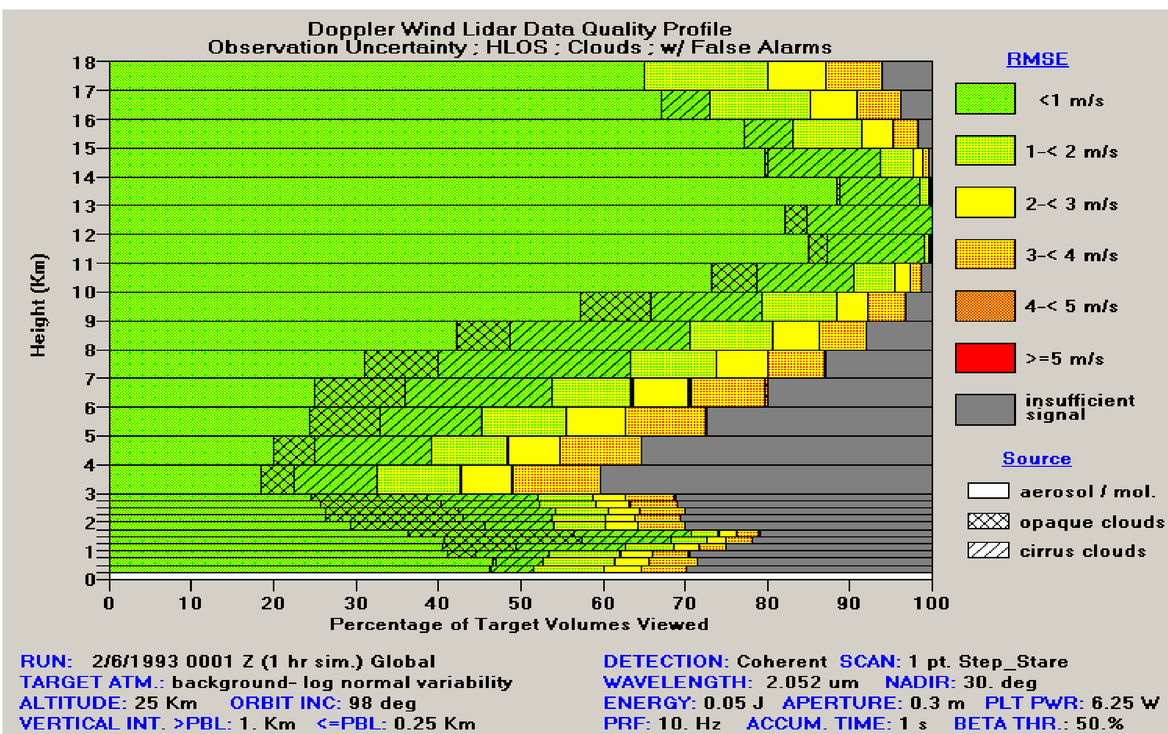

Figure 5. Performance plot of an airborne Hybrid/A direct detection subsystem (weak aerosol regime)