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CHARACTERISTICS AND TRADE-OFFS OF DOPPLER LIDAR GLOBAL WIND PROFILING

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1. Introduction

Accurate, global profiling of wind velocity is highly desired by NASA, NOAA, the DOD/DOC/NASA Integrated Program Office (IPO)/NPOESS, DOD, and others for many applications such as validation and improvement of climate models, and improved weather prediction. The most promising technology to deliver this measurement from space is Doppler Wind Lidar (DWL). The NASA/NOAA Global Tropospheric Wind Sounder (GTWS) program is currently in the process of generating the science requirements for a space-based sensor. In order to optimize the process of defining science requirements, it is important for the scientific and user community to understand the nature of the wind measurements that DWL can make. These measurements are very different from those made by passive imaging sensors or by active radar sensors. The purpose of this paper is to convey the sampling characteristics and data product trade-offs of an orbiting DWL.

2. DWL Wind Measurement

There are several DWL technologies being considered for space. These divide into two groups when considering how the wind measurement degrades as the Signal-to-Noise Ratio (SNR) decreases. The first type of DWL, noncoherent or so-called direct detection DWL, continues to make a wind measurement as the SNR decreases, but with an increasing velocity error that is inversely proportional to SNR. This is the intuitive behavior of a sensor.

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The second type of DWL, coherent detection DWL, naturally makes very accurate wind measurements whenever a successful measurement occurs, but suffers a decrease in the probability of a successful wind measurement as SNR decreases. (see Figure 1) These two types of behavior must be remembered when discussing instrument vs. science product trade-offs. We refer to noncoherent DWL as accuracy challenged with innate good coverage, and coherent DWL as coverage challenged with innate good accuracy. This bifurcation in behavior occurs independently of and after the limitations of clouds and scan patterns are overcome. The trade between higher accuracy and greater coverage is a major consideration in designing a future space-based DWL.

A second difference among DWL technologies is the ability to vary some data processing parameters after the data are downlinked. The DWL technology may or may not allow post-processing changes in the number of lidar shots accumulated per LOS measurement, and in the vertical resolution of the processed data. These flexibilities may be important to data users, such as making opportunistic measurements through holes in clouds.

3. LOS Sampling and Coverage

Unlike space-based passive imaging and active radar sensors, DWL sensors will probe a very small fraction of the earth's atmosphere along cylindrical lines-of-sight (LOS). Each laser shot (Figure 1) will illuminate a footprint on the Earth's surface (and in any horizontal plane above that) that has a diameter of only 5 – 100 m, depending on the exact Doppler lidar technology and on the nadir angle of the beam. For a 400-km orbit height and 45-deg. nadir angle at the spacecraft, each cylindrical laser shot will be 30.3 km long as it slants through 20 km of the atmosphere. The (x,y) location of the wind measurement will change by 26.6 km as the measurement altitude changes by 20 km. The component location changes in the AT and CT directions will each be 18.8 km. The 45-deg. nadir angle at the spacecraft grows to 48.7 deg. in the troposphere due to earth curvature.

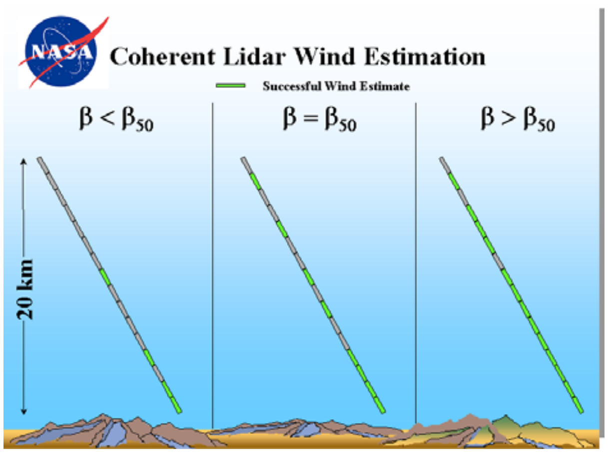

Figure 1. Schematic of a single LOS, range-gated wind profile for a coherent DWL and low/medium/high aerosol reflectance (L to R); where β is the aerosol backscatter coefficient and the subscript 50 denotes that 50% of the wind estimates are expected to be good.

For a 400 km orbit height, the forward motion of the sub-satellite point is 7200 m/s. Realistic laser pulse rates of 10 – 100 Hz yield along-track (AT) footprint spacings of 720 – 72 m. The most likely lidar scanner will have a fixed nadir angle and a variable azimuth angle, resulting in a downward-pointing conical surface from space. The fixed nadir angle will be in the range of 30 – 50 degrees because smaller angles do not sufficiently intercept the desired horizontal wind field, and larger angles lower the signal strength too much through increased atmospheric extinction of the laser beam, and increased inverse range squared losses. Different cross-track (CT) positions will be obtained by changing the scanner's azimuth angle.

Practical DWL technology considerations lead to the combination of 10 – 1000 laser/lidar shots to produce one LOS wind velocity measurement. During this single LOS measurement, the laser/lidar shots to be combined must all point in the same direction. Hence the lidar scanner is stopped during this shot accumulation (step-stare), and a "line" is drawn on the ground parallel to the satellite ground track (Figure 2, the ground track is the x axis). A line representing one LOS wind observation is only 5 – 100 m wide in the CT direction, and may be very long in the AT direction. The AT linear coverage of this line is most likely much less than 100%. Other CT positions may also be chosen for measurement, but the spacecraft velocity, laser pulse rate, and necessary shot accumulation limit the number of CT positions. The AT spacing of the entire shot pattern (8 azimuth angles) is 300 km in Fig. 2. The various CT measurement positions do not occur at the same AT coordinate, but rather are staggered. The maximum possible CT coordinates given the orbit height and scanner nadir angle is ± 414 km. It is misleading to refer

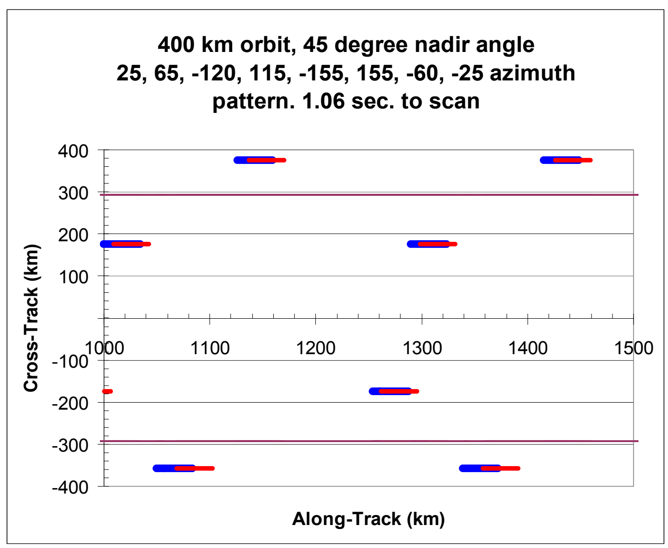

Figure 2. An example of coverage from a DWL with a 25 Hz laser pulse rate and 125 shots accumulated for 36 km long wind lines. The 4 CT positions are at 380, 180, -180, and –360 km. Fore shots are blue and aft shots are red. 0 deg. azimuth points to the right in the AT direction. A scanner azimuth angle change time of 1.06 sec. was assumed. The plotting symbols are much bigger than the actual laser footprint size.

to this “maximum CT reach” of the scanner as the “coverage” for DWLs.

4. Full Horizontal Vector Winds

Each LOS wind measurement relates to a single direction or perspective. Alone, a single LOS is insufficient to resolve the full wind vector. While numerical models will assimilate individual LOS observations, the desired measurement of the horizontal wind requires at least two perspectives. For an orbiting DWL, this is achievable by fore and aft viewing as shown in Figure 2. Since the measurement volume of an accumulated set of LOS observations is shaped like a row of slanted parallel cylinders, the biperspective wind measurement volume is two sets of slanted parallel cylinders. The fore and aft sets of shots are taken within 1-3 minutes of each other and measure approximately the same air volumes. The two lines at CT positions near ±300 km in Figure 2 represent the loci of fore and aft shots with the optimum 90-deg. separation in direction. This angle separation is the projection into a horizontal plane of the actual biperspective angle separation of 60 deg. The biperspective separation angles (projected to horizontal) for the shot pattern in Figure 2 fall into the acceptable range of 50 to 130 deg. This biperspective collocation requires an agile scanner since large azimuthal changes must be accomplished within a second or two.

5. Acknowledgements

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