Lidar and Mission Parameter Trade Study of Space-Based Coherent Wind Measurement Centered on NASA's 2006 GWOS Wind Mission Study Parameters

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Introduction

The global measurement of vertical profiles of horizontal vector winds has been highly desired for many years by NASA[1], NOAA[2] and the Integrated Program Office (IPO) implementing the National Polar-orbiting Operational Environmental Satellite Systems (NPOESS)[3]. Recently the global wind mission was one of 15 missions recommended to NASA by the first ever NRC Earth Sciences Decadal Survey[4]. Since before 1978, the most promising method to make this space-based measurement has been pulsed Doppler lidar[5]. The favored technology and technique has evolved over the years from obtaining line-of-sight (LOS) wind profiles from a single laser shot using pulsed CO_2 gas laser technology[1,2,5] to the current plans to use both a coherent-detection and direct-detection pulsed Doppler wind lidar systems with each lidar employing multiple shot accumulation to produce an LOS wind profile[6]. The idea of using two lidars (hybrid concept) entails coherent detection using the NASA LaRC-developed pulsed 2-micron solid state laser technology[7], and direct detection using pulsed Nd:YAG laser technology tripled in frequency to 355 nm wavelength.

Global Wind Observing System (GWOS)

In anticipation of the NRC Decadal Survey, NASA commissioned several space mission studies to design and cost the expected NRC recommendations. One of these studies was the Global Wind Observing System (GWOS) study utilizing the pulsed hybrid Doppler wind lidar approach. LaRC participated with GSFC on this study and both an instrument design and a mission design were done[7]. The wind measurement requirements for the study were the joint NASA-NOAA "Demonstration" mission measurement requirements[8].

Value of Parameter Trade Studies

Sending remote sensing systems into earth orbit is very expensive. The expense precludes having a trial and error approach to optimizing the sensor parameters, the satellite-orbit parameters, and the mission parameters. A much less expensive approach to parameter optimization is to simulate the earth orbiting sensor's performance and to vary the many parameters looking for the optimum performance while minimizing cost, risk, spacecraft accommodation needs, and development time. One technique to begin to understand the parameter trade space is to choose pairs of parameters whose values are varied while holding a key figure of merit constant. We report in this paper a parameter trade study of parameter pairs for the coherent-detection portion of the desired wind mission. We use wind measurement performance as the figure of merit to remain fixed. We begin all the parameter variations from the GWOS final operating point of the coherent Doppler lidar.

Orbiting Coherent Doppler Lidar Simulation

The computer simulation used for this paper was developed in Microsoft Excel software. The features of Excel facilitate the dual parameter trade studies. The coherent detection Doppler wind lidar performance is taken from the Monte Carlo simulations of Frehlich[10] with treatment of the effect of the "bad" velocity estimates taken from Frehlich and Yadlowsky[11].

Central Operating Point for Trade Studies

Space does not permit a complete description of the GWOS operating point chosen for the trade studies. The orbit height was 400 km and the laser beam nadir angle was 45 deg. Shot accumulation was 60 laser shots which took 12 sec over which the sub-spacecraft point moved forward 85 km. The 2-micron laser emitted 0.25 J pulses at 5 Hz with 180 ns FWHM pulse duration. The receiver mirror diameter was 0.5 m. The measurement height was 5 km and the vertical resolution was 2000 m. The average number of coherent photo-electrons detected per laser shot and from the 2000 m vertical interval (Φ) was 4.5. The statistical percentage of wind measurement attempts that produced a meaningful velocity value near the true value was 95% (b = 0.05). The standard deviation (σ) of the random velocity error (V) of these "good" (G) estimates was 0.77 m/s ($\sigma_{V,G,LOS}$). Including the "bad" 5% of wind estimates (B), projecting into the horizontal plane (HOR), and adding sampling (representativeness) error (S) due to the narrow, 85-km long measurement area raises the total error to 2.1 m/s ($\sigma_{V,G+B+S,\ HOR}$).

Laser Parameter vs. Laser Parameter Trade

Figure 1 shows the trade of laser pulse repetition frequency (PRF) vs. laser pulse energy required to hold the probability of a "good" estimate constant at 95%. The arrow indicates the nominal GWOS operating point of 0.25 J and 5 Hz. Since the shot accumulation time is held constant at 12 sec, the number of accumulated laser shots is proportional to the PRF. The solid line reveals that the required pulse energy is approximately proportional to the inverse square root of the PRF. This is reasonable since the shots are incoherently added in frequency space. The total velocity error remains very close to 2.1 m/s for all values. Not shown here are the many other ramifications of changing PRF, such as laser average power, laser lifetime, data acquisition speed, and data rate.

Laser Parameter vs. Lidar Parameter Trade

Figure 2 shows the trade of receiver optical diameter vs. laser pulse energy, while again holding the parameter b at 0.05. The budgeted standard deviation of the random misalignment of transmitter and receiver axes was held constant at 3.08 microradians, which gave a budgeted 3 dB of SNR loss for the GWOS point design. The required pulse energy rises for smaller diameters due to smaller photon collection area. It also rises for larger diameters due to increasing phase mismatch from the fixed misalignment angle. The total velocity error remained constant.

Laser Parameter vs. Mission Parameter Trade

The trade of laser pulse energy vs. vertical resolution selected during data processing is shown in Figure 3 for constant b = 0.05. The solid line indicates that required pulse energy is approximately proportional to the inverse square root of vertical resolution. Since the backscattered optical power is proportional to the vertical resolution, the square root dependence indicates that the signal coherence length is much smaller than the vertical resolution. Velocity error remained constant.

Conclusions

The value b = 0.05 used herein is conservative in that it is on the poor performance side of a steep performance “cliff”. For example, an increase of only 50% in the aerosol backscatter coefficient would improve b from 0.05 to 0.002 (99.8% good estimates) and would improve $\sigma_{V,G+B+S,\ HOR}$ from 2.1 to 1.0 m/s. Since each trade could be repeated for every possible operating point, we are only beginning to cover all possibilities.

Acknowledgments

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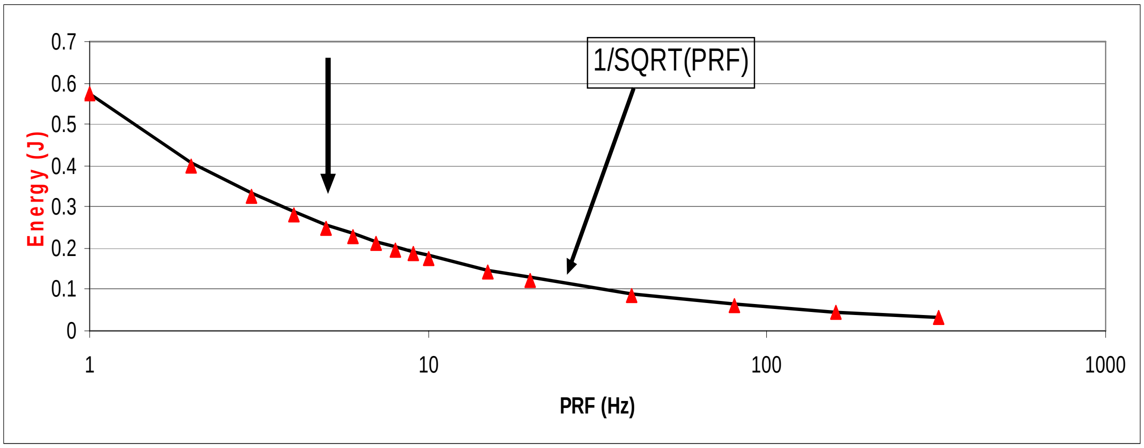

Figure 1. Laser Pulse Energy vs. Laser Pulse Repetition Frequency

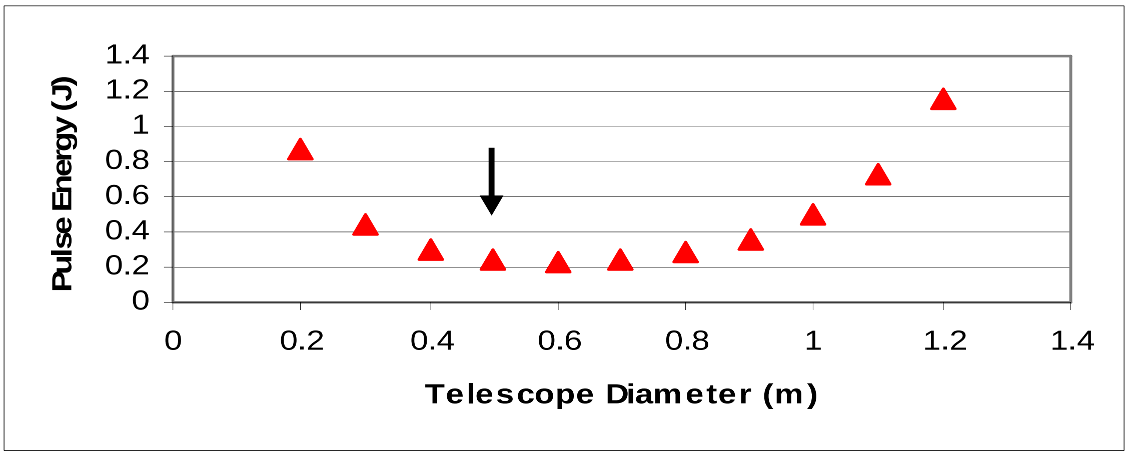

Figure 2. Laser Pulse Energy vs. Receiver Telescope Diameter

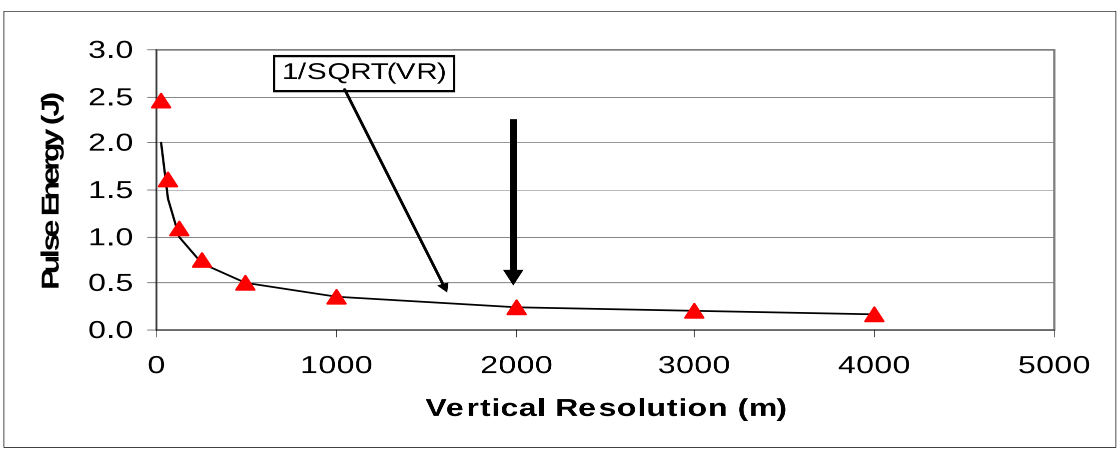

Figure 3. Laser Pulse Energy vs. Vertical Resolution