WIND RETRIEVAL ALGORITHMS FOR THE WIND PRODUCTS OF THE AIRBORNE COHERENT DOPPLER LIDAR

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ABSTRACT

The airborne coherent Doppler lidar could provide the wind velocity relative to the motion of the lidar. The retrieval algorithms are complex corresponding to Ground-based lidar, due to the Doppler shift caused by mobile platform. This article gives a thorough analysis of the wind retrieval algorithms for the wind products of airborne Doppler lidar, include the correction for the lidar velocity measurement. Most of data correction method is introduced in this paper, including the data correction of attitude, velocity, and ground return and so on. Those methods will be necessary for the accuracy improvement of wind detection of airborne Doppler lidar.

1. INTRODUCTION

Atmospheric laser remote sensing can be a powerful motivational tool for science education. Wind measurements with high spatial and temporal resolution can be performed by Doppler wind lidar, which is essential for improving numerical weather prediction models. An airborne Doppler lidar to observe wind profiles downward from an aircraft is developing recently. We will investigate the algorithms required to extract the Doppler shift, compensate for aircraft attitude and velocity, and measure wind profiles through airborne experiments. The instruments measure the wind velocity relative to the motion of the lidar, therefore, the correction for the motion of platform is required, also is used for the attitude correction, ground return signal processing. The Ground-Return (GR) can offer the opportunities to calibrate the airborne or space-based lidar system, due to the uniform backscatter properties and the same detection process to atmospheric signal. The calibration can be done by a combination of information from a Laser Inertial Reference System (IRS), a Global Positioning System (GPS), and Doppler shift information of GR collected by the airborne lidar [1-2]. In the advent of the airborne and space-based Doppler lidar, the GR will be needed for zero-wind calibration of Line-of-Sight-Velocity (LOSV) to insure the full accounting for platform motion. Fig.1 shows the frame of data processing of airborne Doppler lidar, a lot of correction works should be performed before the output of wind products.

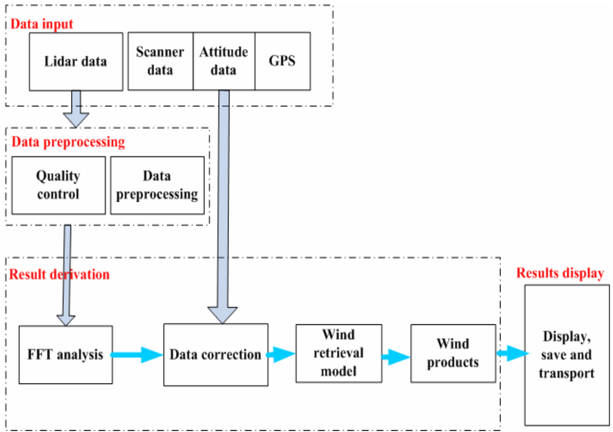

Figure 1. The frame of data processing of airborne Doppler lidar

In this paper, two airborne Doppler lidar data sources were used for the processing analysis. One is from the Airborne Doppler Lidar (ADL) based on the iodine filter and developed by Ocean University of China [3-4]. The airborne campaign was performed on abroad airplane "Y-12", with fixed laser direction to look sideways with 21° nadir angle. Another is from the ALADIN Airborne Demonstrator (A2D) which was developed by DLR as the airborne prototype of ALADIN, with the same detection principle and techniques. Double techniques were used by A2D, combining an aerosol Mie and a molecular Rayleigh receiver to benefit from their complementarities in vertical coverage, corresponding to the fringe image technique based on the Fizeau interferometer and the double edge technique based on the Fabry-Perot interferometer [5-6].

2. THE LOS CALCULATION

The attitude of aircraft can be well described by three angles of pitch, roll and heading (ϕ, θ, ψ) from IRS, which refer to rotations about the respective axes

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starting from a defined equilibrium state, also with a convention definition of the positive direction. A transformation is needed for the vectors transforming from aircraft coordinate system (*X, Y, Z*) to earth coordinate system (*x, y, z*). Euler angles are one of several ways to specify the relative orientation of two such coordinate systems, and it presents the three attitude angles according to the rotation: pitch about the Y-axis, roll about the X-axis and heading about the Z-axis. The transformation matrix of two coordinate systems is calculated according to Euler's rotation theorem following the rotation sequence definition of aircraft, which is shown in Fig. 2.

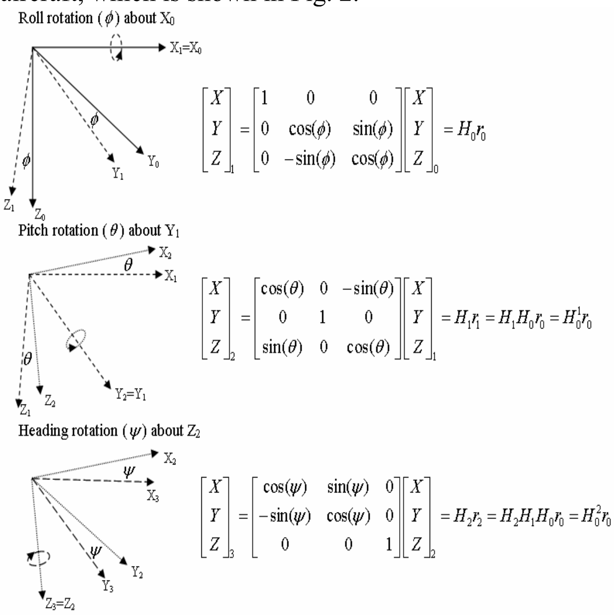

Figure 2. The effects of rotation on vector transformation

Therefore, the LOS pointing direction of laser beam in the earth coordinate system is calculated by:

$$LOS = H_0^2(\psi,\theta,\phi)LOS_0 \qquad (1)$$

Where LOS_0 is the LOS pointing direction of laser beam in the aircraft coordinate system, and it is determined by the telescope installation of the lidar system.

3. AIRCRAFT SPEED CORRECTION

Although the azimuth of the LOS pointing direction is nearly perpendicular to the flight direction, the component from aircraft motion still dominates compared to the component from wind velocity, due to the pitch angle of about 5° and the large aircraft speed over 100 m/s. The accurate zero-wind calibration is necessary and essential important for an airborne Doppler lidar. For airborne system, the LOSV caused by aircraft motion is calculated by the LOS (x_i, y_i, z_i) and aircraft motion velocity (v_x, v_y, v_z) composed of East-West velocity (along x-axis), North-South velocity (along y-axis) and Vertical velocity (along z-axis), which is useful for the velocity correction before the retrieval the wind products.

$$\begin{aligned}\overrightarrow{V_a} &= \overrightarrow{V_x}+\overrightarrow{V_y}+\overrightarrow{V_z}\\ \overrightarrow{LOSV_a} &= \overrightarrow{LOS}\cdot\overrightarrow{V_a}\end{aligned} \qquad (1)$$

Fig.3 shows the nadir angle of the laser emission from the flight campaign of ADL on 3 June 2009, and the LOSV caused by aircraft motion was showed in Fig.4.

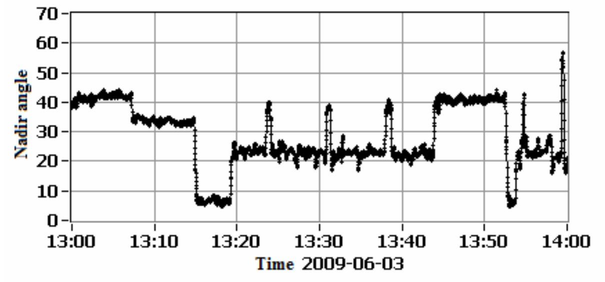

Figure 3. The nadir angle of the laser emission from the flight campaign of ADL on 3 June 2009

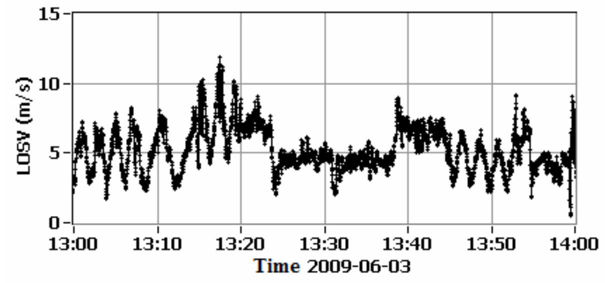

Figure 4. The line of sight velocity caused by aircraft motion from the flight campaign of ADL on 3 June 2009

4. ALTITUDE CORRECTION

The line of sight will change with time, and the altitude of each signal bins also will change. The correction of signal altitude must be carried out due to the distribution of atmospheric aerosols and molecules vary with height. The uniform of the lidar signal altitude is necessary for the following data processing.

The nadir angle of the laser emission in the earth coordinate system could be calculated using both the aircraft attitude data and the laser scanner data, and then the altitude of lidar signal of each bin can be corrected by data interpolation with the uniform altitude resolution. Fig.5 shows how to get a uniform altitude for each lidar signal.

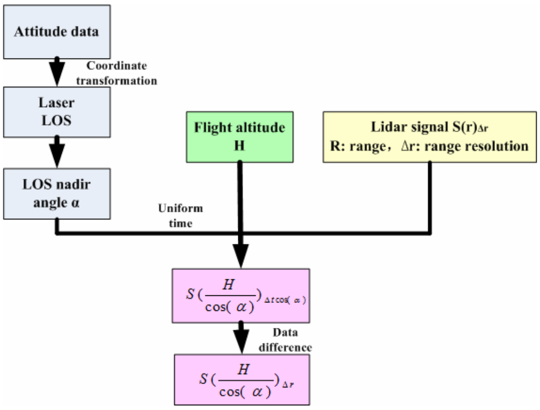

Figure 5. The altitude correction of lidar signal

5. WIND RETRIEVAL MODEL

By using the procedure described above, the azimuth θ and elevation φ of transmitting laser beam in geographic coordinate system are calculated. The wind can be obtained by following formulas after the velocity correction of aircraft movement.

A sine curve is fitted for calculating wind direction and speed by the measured LOS velocity averaged over 8 directions or more directions

$$v_{LOS} = a\cos(\theta - b) + c \qquad (2)$$

Where

$$a = \sqrt{{v_x}^2 + {v_y}^2}\cos\varphi,$$

$$b = \arctan\frac{v_y}{v_x} \qquad (3)$$

$$c = v_z \sin\varphi$$

Then we can get the wind result at each altitude.

$$v = \left(\frac{a}{\cos\varphi\sqrt{1+tan^2 b}}, \frac{atanb}{\cos\varphi\sqrt{1+tan^2 b}}, \frac{c}{\sin\varphi}\right) \qquad (4)$$

Fig.6 shows the calculated LOSV by the correction of attitude, altitude and velocity, changing along azimuth angle with periodicity function. Fig.7 shows the derived wind profile by the wind retrieval model with flight height of about 3 kilometres.

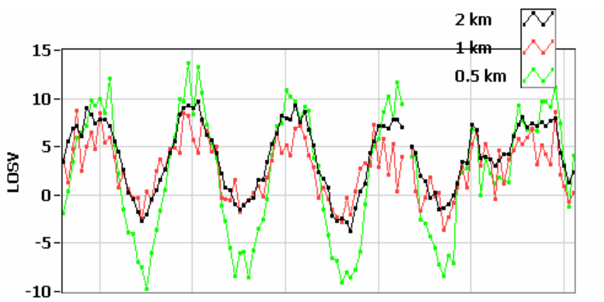

Figure 6. The LOSV changing along azimuth angle

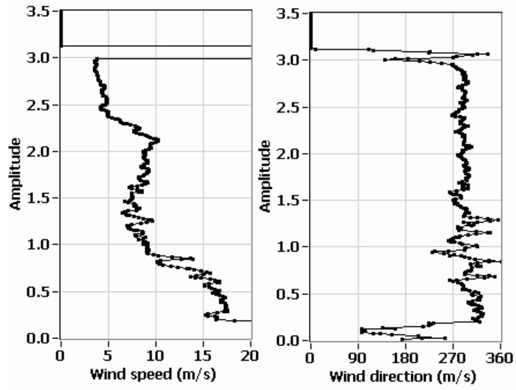

Figure 7. The wind profile derived by the wind retrieval model

6. THE GROUND-RETURN CALIBRATION

The LOSV calculated by aircraft data and the ground return of lidar measurement represent the same LOSV caused by the aircraft motion. For Doppler lidar, the Doppler shift of the returned signal is dominated by the contribution from the aircraft motion. The LOSV calibration caused by aircraft motion can be done by a combination of information from aircraft data and Doppler shift information of GR. This work can be called zero-wind calibration. The validation of zero-wind calibration can be achieved by the comparison of them.

For example, we made an analysis of the zero-wind calibration using the measurement data from A2D airborne campaign. Fig.8 shows the result from a flight on 17 December 2008 at a flight altitude of 7.4 km in the second airborne campaign. The GR mostly came from the sea surface. We assume the influence from the water motion will average to zero when enough measurements are take, even it will not be the fact due to the horizontal component of water motion for off-nadir lidar measurement. Comparing with the LOSV-Aircraft, the bias of LOSV-GR of Mie receiver presents an approximate result, and the LOSV-GR of Rayleigh receiver shows a relation to the intensity of GR. The LOSV-GR of 2 micron indicates a better result than direct detection of A2D, with a good consistency to LOSV-Aircraft.

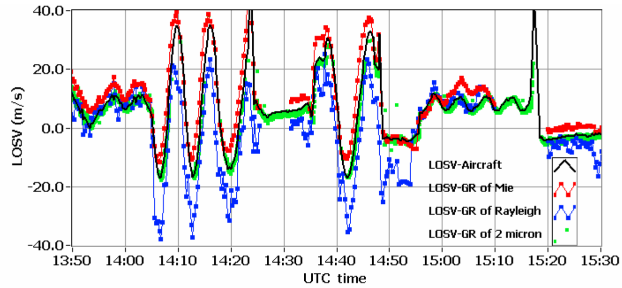

Figure 9. Zero-wind calibration from the flight on 17 December 2008, including LOSV-aircraft (black), LOSV-GR of Mie (red), LOSV-GR of Rayleigh (blue) and LOSV-GR of 2 μm (green).

7. CONCLUSIONS

Airborne Doppler lidar system is a complex system including laser transmitter and receiver platform, laser scanning devices, high-precision inertial measurement, GPS and other subsystems, with multi-measurement data Sources. This paper considers the wind retrieval and correction methods in detail for airborne Doppler lidar data processing. The data processing includes attitude correction, height correction, and the velocity correction, which is important to improve the wind measurement accuracy.

For the atmospheric wind measurement, the zero-wind calibration by the ground-return eliminates the influence from the optics alignment change due to the same detection optics alignment and the same velocity retrieval method for atmospheric signal and GR, and this is a big advantage which can not be achieved by the velocity correction using aircraft attitude data. The aircraft motion compensation can be well performed for entire wind measurement by the zero-wind calibration using GR for the measurement under clear weather condition.

These methods and algorithms are significant for the building of airborne Doppler lidar data processing software.

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ABSTRACT

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INTRODUCTION

Atmospheric laser remote sensing can be a powerful motivational tool for science education. An airborne Doppler lidar to observe wind profiles downward from a plane is developing recently. We will investigate the algorithms required to extract the Doppler shift, compensate for air-plane attitude and velocity, and measure wind profiles through airborne experiment. the instruments measure the wind velocity relative to the motion of the lidar, therefore, the correction for the motion of platform is required, also is used for the attitude correction, ground return signal processing.

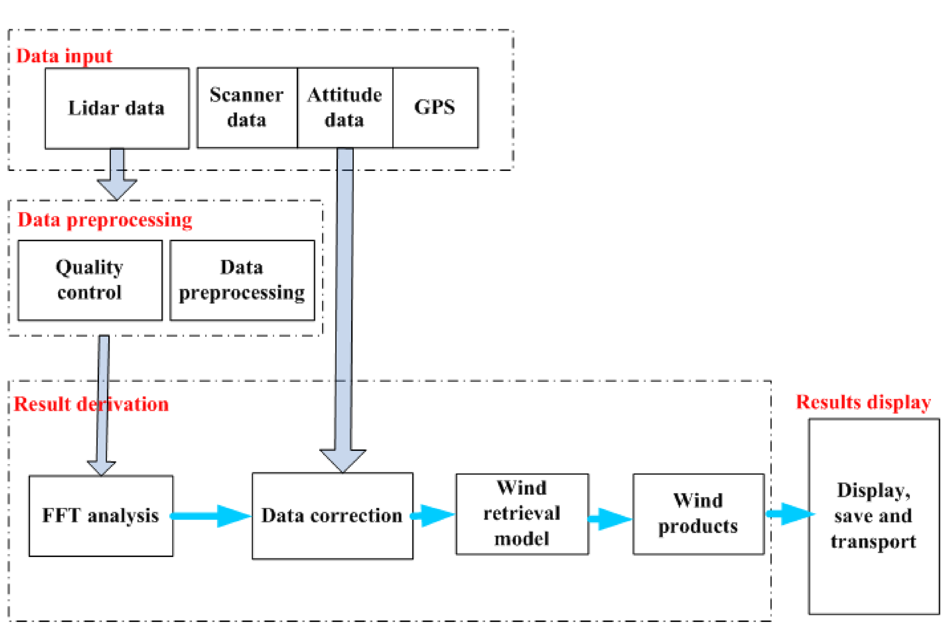


Figure 1. The frame of data processing of airborne Doppler lidar

METHODS

The LOS calculation

The attitude of aircraft can be well described by three angles of pitch, roll and heading from IRS, which refer to rotations about the respective axes starting from a defined equilibrium state, also with a convention definition of the positive direction. we presents the three attitude angles according to the rotation: pitch about the Y-axis, roll about the X-axis and heading about the Z-axis. The transformation matrix of two coordinate systems is calculated according to Euler's rotation theorem following the rotation sequence definition of aircraft, which is shown in Fig. 2.

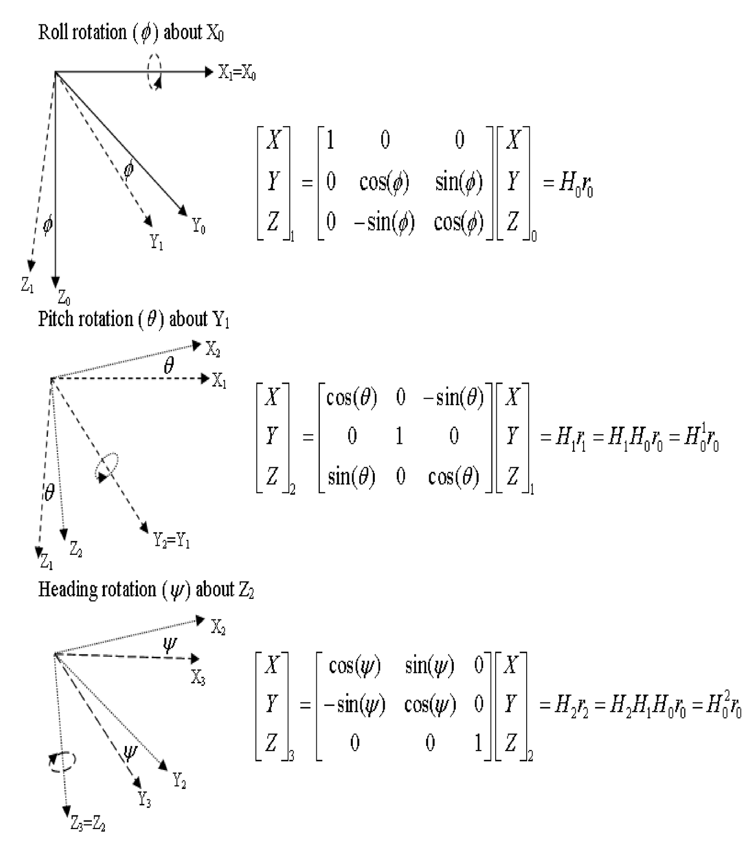


Figure 2. The effects of rotation on vector transformation

Therefore, the direction of transmitting laser during moving measurements can be obtained.

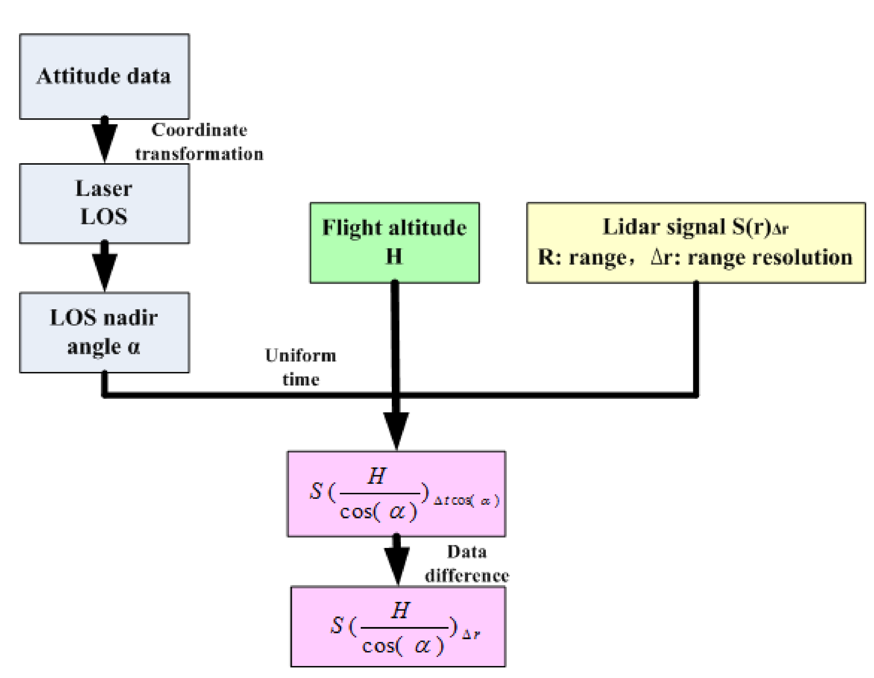
Aircraft speed correction

For the airborne system, the LOSV casuse by aircraft movement can be calculated by the aircraft data including the attitude data for the LOS calculation and the GPS data for velocity calculation, whcih is useful for the velocity correction before the retrieval the wind procucts.

$$\overline{V_a} = \overline{V_x} + \overline{V_y} + \overline{V_z}$$
$$\overline{V_{a\_los}} = \overline{LOS} \cdot \overline{V_a}$$

Altitude correction

A correct altitude correction is necessary in order to get the wind profiles. Figure 3. shows how to get a uniform altitude for each lidar signal.



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Where

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Then we can get the wind result.

$$v = \left(\frac{a}{\cos\varphi\sqrt{1+tan^2 b}}, \frac{atanb}{\cos\varphi\sqrt{1+tan^2 b}}, \frac{c}{\sin\varphi}\right),$$

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The Ground-Return (GR) can offer the opportunities to calibrate the airborne or space-based lidar system, due to the uniform backscatter properties and the same detection process to atmospheric signal.
For Doppler lidar, the Doppler shift of the returned signal is dominated by the contribution from the aircraft motion. The calibration can be done by a combination of information from a Laser Inertial Reference System (IRS), a Global Positioning System (GPS), and Doppler shift information of GR

CONCLUSIONS

The wind field can be derived using the atmosphere aerosol signal with Doppler shift by the coherent Doppler lidar. Most of data correction method is introduced in this paper, including the data correction of attitude, altitude, velocity, ground return and so on. The developing of those algorithms will be necessary for improvement of the wind detection accuracy.

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