S9-4 Wind-Measurement Error of Spaceborne 2 micrometer Coherent Doppler Lidar due to Fluctuation of Spacecraft's Attitude

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1 Introduction

With regard to the Numerical Weather Prediction (NWP) and the global climate model, height profiles of wind are very important parameters as well as those of temperature, humidity and pressure. Global wind observation is also required from the view point of atmospheric sciences for resolving global warming problem.

At present, the wind profiles have mainly been obtained by rawin sondes or geostationary meteorological satellites. In case of rawin sonde, most launch sites are limited in lands, especially in the industrized countries. There is, therefore, a lack of wind data in the oceans and in the developing country. On the other hand, the wind observations using the geostationary meteorological satellites are made by tracking the moving clouds. In this method, however, there are several measurement errors due to uncertainties of cloud heights, cloud's cresation or cloud's extinction. (Totsuka et al., 1999)

Coherent Doppler Lidar (CDL) has a capability of three-dimensional wind velocity measurements and has recently been featured as the powerful instruments in the field of atmospheric science. If it was equipped on the satellite, the global wind observations with the height resolution will be achieved.

In this paper, we would like to report the wind measurement error of spaceborne 2 μ m coherent Doppler lidar to be caused by the fluctuations of spacecraft's attitude.

2 Fluctuations of Doppler shift

For the spaceborne CDL, the laser light scattered from atmospheric aerosols includes two Doppler shift components due to the moving aerosol at the same velocity as the atmospheric wind and the spacecraft's speed. A relation between the velocities and frequncy shifts is written by the following equation;

$$\Delta f_a + \Delta f_s = \frac{2(V+v)}{\lambda}\sin\phi\cdot\cos\alpha \qquad (1)$$

where Δf_a is the Doppler shift frequency for aerosols, Δf_s is the Doppler shift frequency for the spacecraft, λ is a wavelength of the laser transmitter, V is the spacecraft's velocity, v is the wind speed, ϕ is a scan angle, α is an azimuth angle It is obvious to estimate a true wind speed v after subtracting the spacecraft's velocity V. Fig.1 shows a ground truck of the conically-scanned laser beam transmitted from the International Space Station (ISS) / Japanese Experiment Module (JEM) / CDL, where λ =2.06 μ m, V =7 Km/sec, ϕ =30 deg., the changes of Doppler shift frequencies calculated by Eq.(1) is shown in Fig.2 associated with the conical scanning.

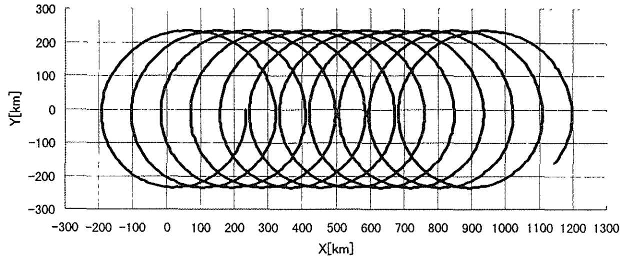

Figure 1.Ground truck (Indication time is 139[s])

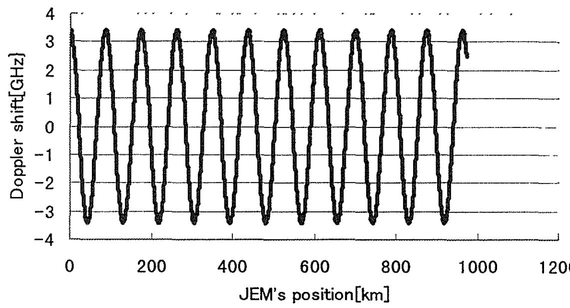

Figure 2. ISS/JEM's Doppler shift change (Indication time is 139[s])

In general, the attitude of ISS/JEM isn't constant. So, it is necessary to evaluate how large the fluctuation of Doppler shift frequency caused by it will be. This is important when we select the bandwidths of amplifier and photo-mixer used in the heterodyne receiver. Fig.3 schematically shows a relation between ISS/JEM's attitude, X axis, Y axis and altiutde. X corresponding to a rolling angle and Y a pitching angle are derivated as Eq. (2) and Eq. (3), respectively.

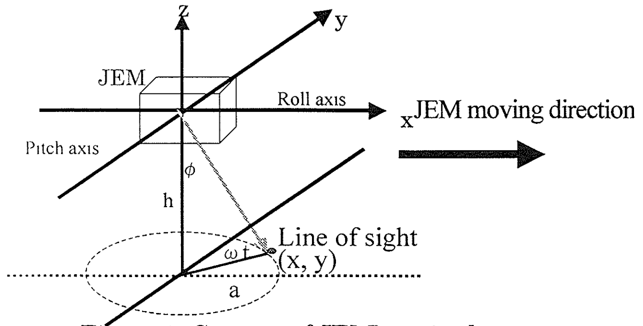

Figure 3. Concept of JEM's attitude

$$X=\frac{\left(-a^2z\cos(\theta)\sin(\theta)-h^2z\cos(\theta)\sin(\theta)\pm h\sqrt{\left(-h^2y^2\cos(\theta)^2+a^2z^2\cos(\theta)^4+a^2y^2\sin(\theta)^2+2a^2z^2\cos(\theta)^2\sin(\theta)^2+a^2z^2\sin(\theta)^4\right)}\right)}{\left(h^2\cos(\theta)^2-a^2\sin(\theta)^2\right)} \quad (2)$$

$$Y=y$$

$$X=x \quad (3)$$

$$Y=\frac{\left(a^2z\cos(\theta)\sin(\theta)+h^2z\cos(\theta)\sin(\theta)\pm h\sqrt{\left(-h^2x^2\cos(\theta)^2+a^2z^2\cos(\theta)^4+a^2x^2\sin(\theta)^2+2a^2z^2\cos(\theta)^2\sin(\theta)^2+a^2z^2\sin(\theta)^4\right)}\right)}{\left(h^2\cos(\theta)^2-a^2\sin(\theta)^2\right)}$$

Where θ is pitching angle or rolling angle. And Table 1. gives the JEM's attitude given by NASDA

Table 1. JEM attitude (NASDA et al.,1998)

Orbital height	407[km]
JEM's velocity	7[km/s]
Period	5400～5600[s]
Inclination	51.6deg
Range of allowble attitude Rolling: ±15deg Pitching: -20～+15	
Attitude rate	±0.01deg/sec

In case of occurances of attitude fluctuation, α and ϕ must change. Using above Equations, we estimated JEM's Doppler shift change with varying of pitching angle. A calculated result is shown in Fig.4.

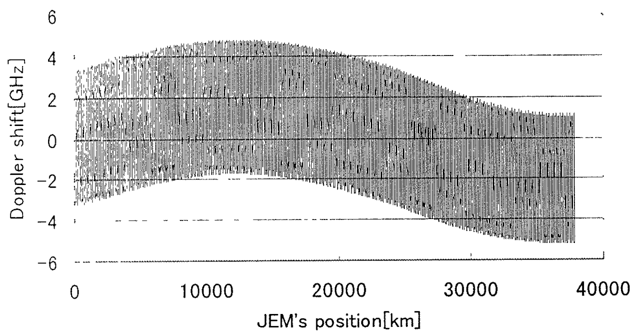

Figure 4. Doppler shift change during 1 period

3 Wind measurement error due to fluctuation of JEM's attitude

When the atittude of ISS/JEM changes, path-lengths of transmitted and received light also change. This gives rise to a change of received power, namely, the signal-to-noise ratio (SNR) does, and the wind measurement error is finally enhanced. SNR is described in equation (4).

$$SNR=\frac{\eta\lambda P_r(R)}{hcB}=\frac{\eta\lambda KE_t\beta(R)AT(R)^2}{2hBR^2} \quad (4)$$

where η is detection efficiency, P_r (R) is receiving power, h is Planck's constant, c is the light of speed, B is the system bandwidth, K is the effective collection efficiency, E_t is transmitted pulse energy, β is the backscatter coefficient, A is the telescope area, T is the atmospheric transmittance, R is the range to the target. We use Eq. (4) to evalute the SNR, and input to the Eq.(5). Using Eq.(5), we can obtain the wind measurement error. Eq.(5) is the following. (Thomas J. Kane et al.,1984)

$$\delta v=\frac{\lambda}{4\pi}\left(\frac{f_s}{2NL\Delta t}\right)^{\frac{1}{2}}\left(2\pi^{\frac{3}{2}}W+\frac{16\pi^2W^2}{(SNR)}+\frac{1}{(SNR)^2}\right)^{\frac{1}{2}}$$

$$W=\frac{\left(v_{bm}^2+v_{atm}^2\right)^{\frac{1}{2}}}{v_{Ny}} \quad (5)$$

where f_s is the sampling frequency, N is the number of pulse averaged, L is the ratio of the range gate to the length of a pulse, Δt is the duration of a transmitted pulse. W is a measure of the frequency spread of the return signal in the absence of any noise. V_{Ny} is the maximum unaliased velocity as determined by the Nyquist criterion and V_{bm} is the velocity uncertainty corresponding to the bandwidth of the transmitted pulse and V_{atm} is the standard deviation of the distribution in the measured volume due to turbulence and wind shear. From Eqs.(4) and (5), we can undestand that if the fluctuation of JEM's attitude was occurred, wind measurement error will be change with non-fluctuation of attitude.

Reference

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