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Atmospheric Measurement Techniques
Discussions
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Interactive comment on "Observations of water vapor mixing ratio and flux in Tibetan Plateau" *by* S. Wu et al.

S. Wu et al.

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Thank you for your review of our manuscript. We greatly appreciate the substantial amount of time and effort that you dedicated to this review process. Here we provide the response to you and you can also refer to the mark kept revision of PDF file in "Supplement". Thanks again.

This manuscript describes a water vapor Raman lidar system and some of its measurements in the Tibetan Plateau. The language of the manuscript is unfortunately poor and will require substantial copy editing before being acceptable for publication. But the main problems I have with the manuscript are related to its contents: (1) It contains only insufficient references to the state-of-the-art of lidar. Being probably the ground

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based Raman lidar at the site at the highest altitude worldwide, one would expect references to other mountain-based water vapor lidars (Zugspitze and Jungfraujoch in Europe, Mauna Loa in Hawaii, USA, more?). Furthermore, special issues regarding the meteorological conditions and problems regarding the ambient conditions at the ground and how the authors solved these issues are mostly missing and should be discussed in much greater detail.

A: The references about the mountain-based lidar located at Zugspitze and Jungfraujoch in Europe, Mauna Loa in Hawaii, USA are cited in revision.

1. DeFoor, T. and Robinson, E.: Stratospheric lidar profiles from Mauna Loa Observatory, winter 1985âĂŘ1986, Geophys. Res. Lett., 14, 618-621, 1987.

2. DeFoor, T. E., Robinson, E., and Ryan, S.: Early lidar observations of the June 1991 Pinatubo eruption plume at Mauna Loa Observatory, Hawaii, Geophys. Res. Lett., 19, 187-190, 1992.

3. Klanner, L., Trickl, T., and Vogelmann, H.: Combined Raman lidar and DIAL sounding of water vapour and temperature at the NDACC station Zugspitze, 15414, 2010

4. Larchevêque, G., Balin, I., Nessler, R., Quaglia, P., Simeonov, V., van den Bergh, H., and Calpini, B.: Development of a multiwavelength aerosol and water-vapor lidar at the Jungfraujoch Alpine Station (3580 m above sea level) in Switzerland, Appl. Opt., 41, 2781-2790, 2002.

For the solution of the special issues regarding the meteorological conditions and problems regarding the ambient conditions at the ground: In the WACAL system, since the laser chiller inside the cabin generate a lot of heat, which is harmful for the operation of the laser, it is essential to cool the air in this cabin. The ventilation facility with high ventilation rate fan is taken into consideration, which plays a very practical role in the high elevation and low air pressure field experiment, e.g. the Tibetan Plateau field campaign. Moreover, to avoid the arc discharge in the high voltage power supplier in

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the low air pressure conditions, the voltage of the lamp in amplifier and oscillator stage was decreased. Please refer to the first paragraph of the section 2 “Lidar technology and methodology”.

(2) Important information on how the results have been derived is missing at several points.

A: Revised. The manuscript has been rewritten and the calculation methods used for the results have been described in details. Please refer to the revision.

(3) The whole section about the latent heat flux measurements is unclear to me because essential information is missing.

A: Revised. In this section, we add some new results and explain the calculation method used for the flux. Please refer to the revision. “Result from the unique atmospheric characteristics and heating power of the Tibetan Plateau, the longtime serials observation of vertical wind velocity is required. From this observation, the turbulence, updraft and downdraft at different time period in one day can be detected and analyzed. For this purpose, one case study on 15 July 2015 is provided in Fig. 9. During 0000 LST and 0927 LST, because of the low temperature and rare human and industrial activities, the boundary layer in Tibetan plateau is very low and cannot be detected by CDL with a detection blind region of 90 m. During the daytime, the turbulence can be found and the value of the vertical wind velocity is between ±1 m/s . However, the turbulence in nighttime is rare and the vertical wind velocity is between 0 m/s and 1 m/s , which indicates that the upwelling of the atmosphere on the Tibetan Plateau.

In term of the vertical velocity and vertical water vapor flux, one case study on 15 August 2014 is presented below. Figure 10(a) shows the time serials of range correction signal measured by WACAL and Fig 10(c) is the time serials of the vertical velocity profile of 164 minutes obtained from the Coherent Doppler Wind lidar. By combining the water vapor mixing ratio (Fig. 10(b)) and vertical wind velocity, the vertical water vapor flux can be calculated and the temporal development is shown in Fig. 11. The temporal resolution âŰşt and spatial resolution âŰşr of the vertical wind velocity is 22 s and 13 m respectively. And the original âŰşt and âŰşr of the water vapor mixing ratio is 10 min and 3.75 m respectively. However, in order to sample the turbulent processes, the simultaneous observations with high and same âŰşt and âŰşr by WACAL and CDL are required. For this purpose, the âŰşt and âŰşr of WACAL are adjusted to be equal to those of CDL by means of interpolation. The time serials of water vapor mixing ratio shown in Fig. 10(b) indicates that the water vapor mixing ratio inside clouds which are located at the height of 1.0 km to 1.5 km at time period from 21:40 LST to 22:25 LST is higher than in atmosphere around. The water vapor mixing ratio in the cloud is around 8.63±1.66 . According to Fig 10(a), it started to rain at about 22:00 LST. From these figures, it is noted that the water vapor kept upwelling and depositing and the flux is about 1.20±2.48 during 21:03 and 22:00 LST before the raining. Meanwhile, in the process of raining, the water vapor inside the clouds kept depositing and the flux is about -3.37±2.24 . Note that because of the coverage and blocking of the raindrop gathered on the windows of WACAL, the water vapor mixing ratio measured during the time period of 22:05 LST to 22:10 LST should be used carefully and is removed during the calculation of the flux. Consequently, a small-scale water vapor cycling was formed partly and the upwelling and deposition of the water vapor were monitored."

Specific points:

Page 11927, line 8: References to previous intercomparison studies with water vapor lidar systems, e.g., within the IHOP_2002 campaign (Behrendt et al., JTech, 2007a,b) and the COPS campaign (Bhawar et al., QJRMS, 2011) should be included.

A: Revised. We added some new references in the revision. Please refer to the 1st paragraph of the section 1 "Introduction".

1. Behrendt, A., Wulfmeyer, V., Bauer, H.-S., Schaberl, T., Di Girolamo, P., Summa, D., Kiemle, C., Ehret, G., Whiteman, D. N., and Demoz, B. B.: Intercomparison of water vapor data measured with lidar during IHOP_2002. Part I: Airborne to ground-based

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lidar systems and comparisons with chilled-mirror hygrometer radiosondes, J. Atmos. Oceanic Tech., 24, 3-21, 2007a.

2. Behrendt, A., Wulfmeyer, V., Schaberl, T., Bauer, H.-S., Kiemle, C., Ehret, G., Flamant, C., Kooi, S., Ismail, S., and Ferrare, R.: Intercomparison of water vapor data measured with lidar during IHOP_2002. Part II: Airborne-to-airborne systems, J. Atmos. Oceanic Tech., 24, 22-39, 2007b.

3. Bhawar, R., Di Girolamo, P., Summa, D., Flamant, C., Althausen, D., Behrendt, A., Kiemle, C., Bosser, P., Cacciani, M., and Champollion, C.: The water vapour intercomparison effort in the framework of the Convective and OrographicallyâĂŘinduced Precipitation Study: airborneâĂŘtoâĂŘgroundâĂŘbased and airborneâĂŘtoâĂŘQ. J. R. Meteorol. Soc., 137, 325-348, 2011.

Page 11927, line 11: This statement is not true I think. Please revise or add references as proof.

A: Revised. We deleted this statement.

Page 11927, line 17: Please add more recent papers on water vapor DIAL.

A: Revised. Some recent papers about DIAL have been cited in the revision. The citation will be list below:

1. Vogelmann, H. and Trickl, T.: Wide-range sounding of free-tropospheric water vapor with a differential-absorption lidar (DIAL) at a high-altitude station, Appl. Opt., 47, 2116-2132, 2008

2. Wirth, M., Fix, A., Mahnke, P., Schwarzer, H., Schrandt, F., and Ehret, G.: The airborne multi-wavelength water vapor differential absorption lidar WALES: system design and performance, Appl. Phys. B, 96, 201-213, 2009.

Please refer to the 1st paragraph of the section 1 “Introduction”.

Page 11927, line 28: Please add more recent papers on water vapor Raman lidar.

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Even stratospheric water vapor measurements with Raman lidar have been reported meanwhile.

A: Revised. Some new papers about water vapor Raman Lidar have been cited in the revision. The citation will be list below:

1. Leblanc, T., McDermid, I. S., and Aspey, R. A.: First-year operation of a new water vapor Raman lidar at the JPL Table Mountain Facility, California, J. Atmos. Oceanic Tech., 25, 1454-1462, 2008.

2. Dinoev, T.: Automated Raman lidar for day and night operational observation of tropospheric water vapor for meteorological applications, 2009. ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, 2009.

3. Dinoev, T., Simeonov, V., Arshinov, Y., Bobrovnikov, S., Ristori, P., Calpini, B., Parlange, M., and Van den Bergh, H.: Raman Lidar for Meteorological Observations, RALMO-Part 1: Instrument description, Atmos. Meas. Tech., 6, 1329-1346, 2013. Please refer to the end of the 1st paragraph of the section 1 “Introduction”.

Page 11928, first paragraph: Please add references for these statements. A: Revised. This paragraph has been rewritten and moved to the end of the introduction section. Some references have been cited. Please refer to the revision.

Page 11928, line 14: Which type of radiosondes is used?

A: The type of the radiosonde is GTS1 type. The radiosonde provides temperature accuracy of , relative humidity accuracy of and pressure accuracy of . The information about the radiosonde has already been added in the revision.

Page 11928, line 17: Please add references.

A: Revised. This paragraph has been rewritten and moved to the end of the introduction section. Some references have been cited. Please refer to the revision. Kuwagata, T., Numaguti, A., and Endo, N.: Diurnal variation of water vapor over the central Tibetan

Plateau during summer, J. Meteorol. Soc. Jpn., 2, 79, 401-418, 2001.

Page 11929, second paragraph: Please add references.

A: Revised. Some new references have been added in the revision. And the references will be listed below:

1. Demtröder, W.: Molecular physics: theoretical principles and experimental methods, Wiley VCH, Weinheim, 2005.

2. Demtröder, W.: Laser spectroscopy: basic concepts and instrumentation, Springer Science & Business Media, 2013.

3. Inaba, H. and Kobayasi, T.: Laser-Raman radarâĂŤLaser-Raman scattering methods for remote detection and analysis of atmospheric pollution, Opto-electron., 4, 101-123, 1972.

4. Inaba, H.: Detection of atoms and molecules by Raman scattering and resonance fluorescence. In: Laser monitoring of the atmosphere, Springer, Berlin Heidelberg, 153-236, 1976.

Page 11929: Please explain the setup of the lidar (telescope characteristics) at one point and not piece by piece in different paragraphs.

A: Revised. Please refer to the 2nd and 3rd paragraphs in section 2 “Lidar technology and methodology”. The brief introduction of the WACAL system has been provided. And for the details of the WACAL, please refer to this paper shown below:

Wu, S., Song, X., Liu, B., Dai, G., Liu, J., Zhang, K., Qin, S., Hua, D., Gao, F., and Liu, L.: Mobile multi-wavelength polarization Raman lidar for water vapor, cloud and aerosol measurement, Opt. Express, 23, 33870-33892, 2015.

Page 11930, line 14: Is there a risk of temperature sensitivity with using a water vapor filter with such a small bandwidth (Whiteman, Applied Optics, 2003a,b)? Please comment and explain why you selected these specifications.

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A: Whiteman evaluated the temperature-dependent lidar equations of the traditional Raman lidar in 2003 (Whiteman, Applied Optics, 2003a,b). According to the study of Whiteman, the ratio of transmitted intensities between 200K and 300K for the water vapor passbands at central wavelength of 407.50nm is close to 1 (as figure shown below, Fig. 4 in Whiteman, Applied Optics, 2003a). The relative change of the transmitted intensity could reach 12% for 0.1 nm bandwidth as confirmed by Whiteman Opt. Let., 1993 and Whiteman, Applied Optics, 2003. For that reason, broader than 0.2 nm (at FWHM) spectral functions for water vapor channel were considered in the design of the water vapor polychromator. In case of nitrogen and oxygen, the temperature dependence decrease for a bandwidth narrower than 1 nm. A bandwidth of 0.3 nm defines less than 0.39 % variation of the transmitted intensity for nitrogen and less than 1.39 % for oxygen (Whiteman, Opt. Let., 1993). As a consequence, the temperature has slight impact on WACAL and the effect can be ignored. Please refer to the Fig. 1 of the response.

Page 11930: Please explain all parameters used in the equations.

A: Revised. All of the parameters used in the equations have been explained and please refer to the revision.

Page 11931 (and elsewhere): Please add references for all equations which are not new and have been taken from previous publications.

A: Thanks for your suggestion and we have added the references in the revision.

Page 11931, line 14: Please add reference for this statement.

A: The type of the radiosonde is GTS1 type. The radiosonde provides temperature accuracy of , relative humidity accuracy of and pressure accuracy of . The information of the radiosonde was from the manufacturer of radiosonde.

Page 11931, equation 7: Where does the parameter D come from? Does it account for an offset of the radiosonde or the lidar of RS?Was the lidar data corrected for deadtime

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effects of the detector? Please comment on these points in the manuscript.

A: Revised. D is the offset and determined as -0.34. Result from the different observation stations of the WACAL and radiosonde and the WACAL system error, the offset D exists. And yes, it account for an offset of the radiosonde or the lidar of RS.

Yes, the lidar data was corrected for deadtime effects as shown in Eq. (9). All of the comment of these points has been added in the revision.

Page 11931, equation 14: Where does this equation come from? Commonly, latent heat flux measurements with a combination of water vapor lidar and Doppler lidar (all references to previous publications are missing here) are based on correlating vertical wind data and moisture data of the same very high temporal resolution (typically 10 s in order to sample the turbulent processes reasonable well). Here it seems to me that you used data with much lower resolution. Then one would expect that the average vertical wind is zero in the mean. The only exception is found in cases where updrafts are localized due to the orography. Is this the case here? Or did you use wind data with high resolution but moisture data with low resolution? This would be questionable, see comments below regarding Figs. 8 and 9.

A: The Eq. (14) has been changed as and the calculation can be referred to Giez et al., 1999. For the consistency of the symbols, the symbols in Eq. (14) are different from the original paper (Giez et al., 1999).

Yes, the temporal resolution of the water vapor mixing ratio is not high enough for sampling the turbulent process because of the low SNR of Raman lidar. But since this is a night time scene, there is likely low or no turbulence, and it is justified to use average values in Eq. (14) to estimate the mean local water vapor mass flux. We also tried to improve the temporal resolution of the water vapor mixing ratio by means of shifted average and interpolation to shorten the accumulation time. The temporal resolution (âŰşt) and spatial resolution (âŰşr) of the vertical wind velocity is 22 s and 13 m respectively. And the original âŰşt and âŰşr of the water vapor mixing ratio is 10 min and 3.75 m respectively. Furthermore, in order to sample the turbulent processes, the simultaneous observations with high and same âŰşt and âŰşr by WACAL and CDL are required. For this purpose, the âŰşt and âŰşr of WACAL are adjusted to be equal to those of CDL by means of interpolation. The results should be referred to the Fig. 10(a)(b)(c) in the revision.

Page 11936, equation 15: How large is the blocking of the elastic light in the signal of the Raman channels? If the blocking is too low, elastic signal leakage in the water vapor data will cause a moist bias of the measured data in clouds.

A: Sorry for this misunderstanding. In WACAL, two IFs are used in Water vapor Raman channel. So as to Nitrogen Raman channel. The OD of one IF is 5, so the total OD with two IFS is higher than 10, which is enough for the Raman backscatter detection.)

Page 11937: How stable is the lidar calibration in time?

A: Aiming at validating the calibration of water vapor mixing ratio, the scatter diagram based on the calibrated lidar data and radiosonde data measured is drawn in Fig. 4. And the test routines of validation are different from the calibration test routines. The validation test was operated from 10 July 2014 to 16 August 2014. According to the figure, the correlation coefficient is 0.94 and mean deviation is 0.77 . Considering the time difference (∼1.5h) between the observation of the WACAL and that of the radiosonde, the correlation coefficient and deviation are acceptable. As a conclusion, the calibration of the water vapor mixing ratio is accurate enough for the routine observation.

Figure 2: Which heights did you use for the intercomparisons? A distance of 16 km is much too large to expect the same moisture in the convective boundary layer because differences in land-surface properties (soil moisture, vegetation, orography) will cause different surface fluxes. Only comparisons in the free troposphere are acceptable because the moisture in these heights is dominantly influences by advection. How many days/profiles are used for this plot? What is the temporal and range resolution of the data?

A: The heights of water vapor mixing ratio data used for the intercomparisons and calibration is between 2 km and 6 km, which is free of or slightly effected by the boundary layer. The days have already been listed in Table 4 in the revision. The range resolution of water vapor mixing ratio measured by the WACAL is 3.75m. However, because of the data missing in certain height, the range resolution of water vapor mixing ratio measured by radiosonde is not consistent. In order to ensure the accuracy of the calibration, the water vapor mixing ratios at the same height are used.

Table 4 Period of time of the simultaneous observations

May, 2014 12 21 22 26 27 28 29 31

June, 2014 3 4 5 6 7 8 9 10 12 14 15 16 17 18 20 23

Figure 3: Information on date of the measurements, period, resolution is missing.

A: The measurement was operated on 12 June 2014, Qingdao (36.17°N, 120.5°E). The integration time of the profile is about 2h.

Figure 4: Information on date of the measurements, period, resolution is missing. How many days/profiles are used for this plot? What is the temporal and range resolution of the data?

A: The water vapor mixing ratio data used in the validation were obtained from 10 July 2014 to 16 August 2014 in Nagqu. The measurement time was from about 21:30 LST to 23:00 LST. During the expedition experiment campaign in Nagqu, except for the data missing, the water vapor mixing data measured by WACAL and radiosonde at the same heights are used for the validation. So 44 days and 167 cases are used for this plot. The original temporal and range resolution of the data measured by WACAL is 1 h and 3.75 m respectively. And the original range resolution of the data measured by radiosonde is 6 m.

Figure 5: Information on measurement periods and range resolution is missing. What were the launching times of the sondes?

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A: The launching time of the sondes is 1915 LST every day. The original range resolution of the sondes is about 6 m.

Figure 6: This is no diurnal variation (variation within the course of one or several days related to different daylight conditions). This is the moisture development within the period of several days (how many?). How many profiles have been measured on each day? What are the measurement periods of the lidar (averaging over which times)?

A: In Fig. 6(a), water vapor mixing ratio data measured in 44 days (10 July to 16 August) are used. There 10 profiles have been measured on each day. The measurement period of the WACAL is from 21:30 LST to 23:00 LST and the temporal resolution of water vapor mixing ratio is about 20 min.

Figure 7: What is new here? Merge with figure 3?

A: In Fig. 7, the SNRs of Raman signal of nitrogen and water vapor and the relative error of the calculated water vapor mixing ratio are presented. These consequences can be used for error analysis and indicating the capability of the WACAL. However, the result in Fig. 3 shows the correction of the dead-time effects, which is different from the results in Fig. 7.

Figures 8 and 9: Are you using a constant water vapor profile here? Then the results would be wrong because also the atmospheric moisture changes when the wind changes. Figure 8: Is the moisture profile from the lidar? What is the measurement period? What are the error bars? How about incomplete overlap close to the ground?

A: No, the water vapor profile here is not a constant. We also provide the time serials of water vapor mixing ratio in Fig. 10(b) in the revision. The temporal resolution ( ) and spatial resolution ( ) of the vertical wind velocity is 22 s and 13 m respectively. And the original and of the water vapor mixing ratio is 10 min and 3.75 m respectively. However, in order to sample the turbulent processes, the simultaneous observations with high and same and by WACAL and CDL are required. For this purpose, the and of WACAL are adjusted to be equal to those of CDL by means of interpolation. The results should be referred to the Fig. 10(a)(b)(c) in the revision. Please refer to the revision. The water vapor mixing ratio in Fig. 10 is measured by WACAL. The incomplete overlap will be provided in the Fig.2 of the response.

It should be noted that the water vapor mixing ratio below 200 m is obtained by the combination of data from radiosonde and WACAL.

Technical corrections:

“Lidar” should always be written “lidar”.

A: Yes, Thanks and we have corrected it in the revision.

Please use even values for the labels of the plots, e.g., for the times in Figs. 8 and 9.

A: Yes, Thanks and we have revised the labels of these figures in the revision.

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/8/C4705/2016/amtd-8-C4705-2016-supplement.pdf

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Interactive comment on Atmos. Meas. Tech. Discuss., 8, 11925, 2015.

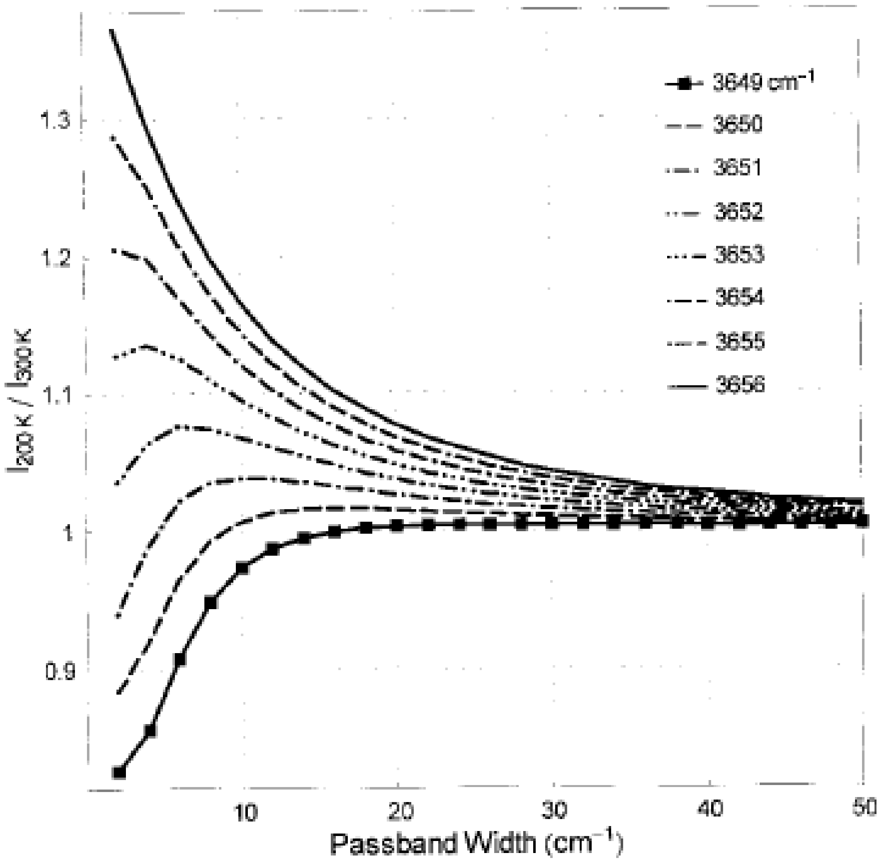
3649 cm^{-1}
3650
3651
3652
3653
3654
3655
3656
1.3
1.2
1.1
1
0.9
$I_{200\,K} / I_{300\,K}$
10
20
30
40
50
Passband Width (cm^{-1})

Fig. 1.

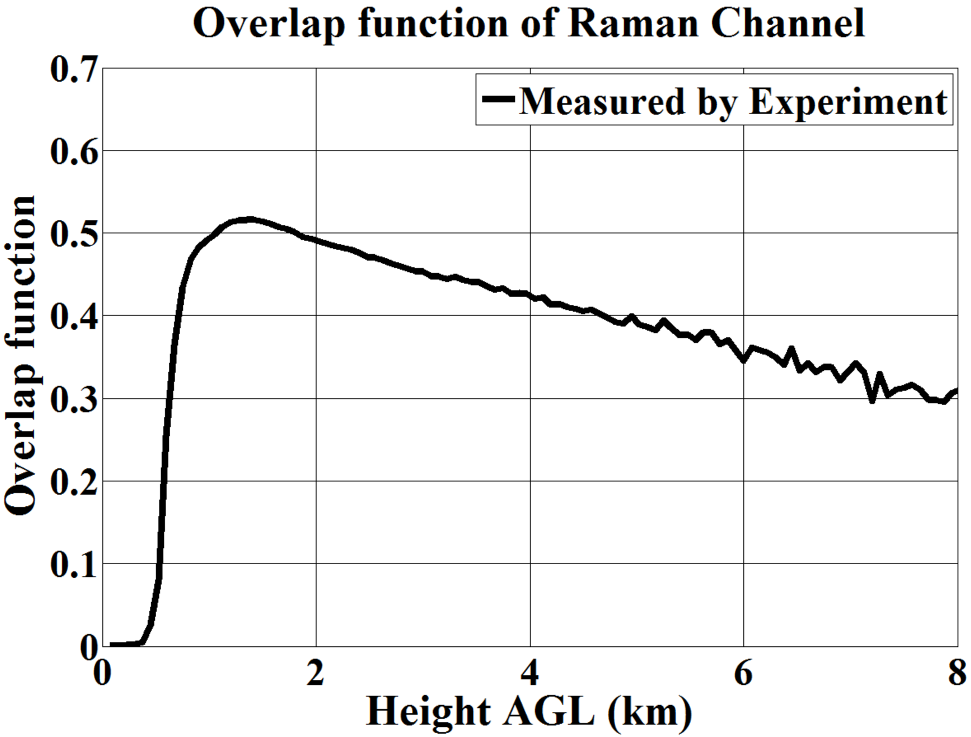
Overlap function of Raman Channel
Measured by Experiment
Overlap function
Height AGL (km)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
2
4
6
8

Fig. 2.