Atmospheric Monitoring in the TA experiment

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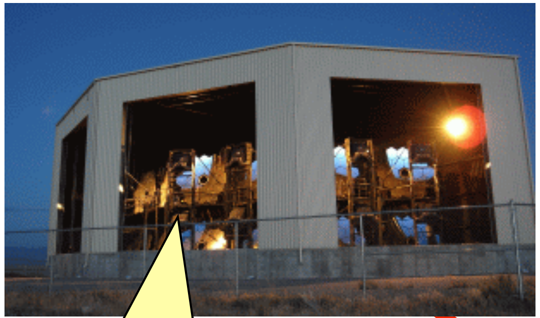
and the TA collaboration

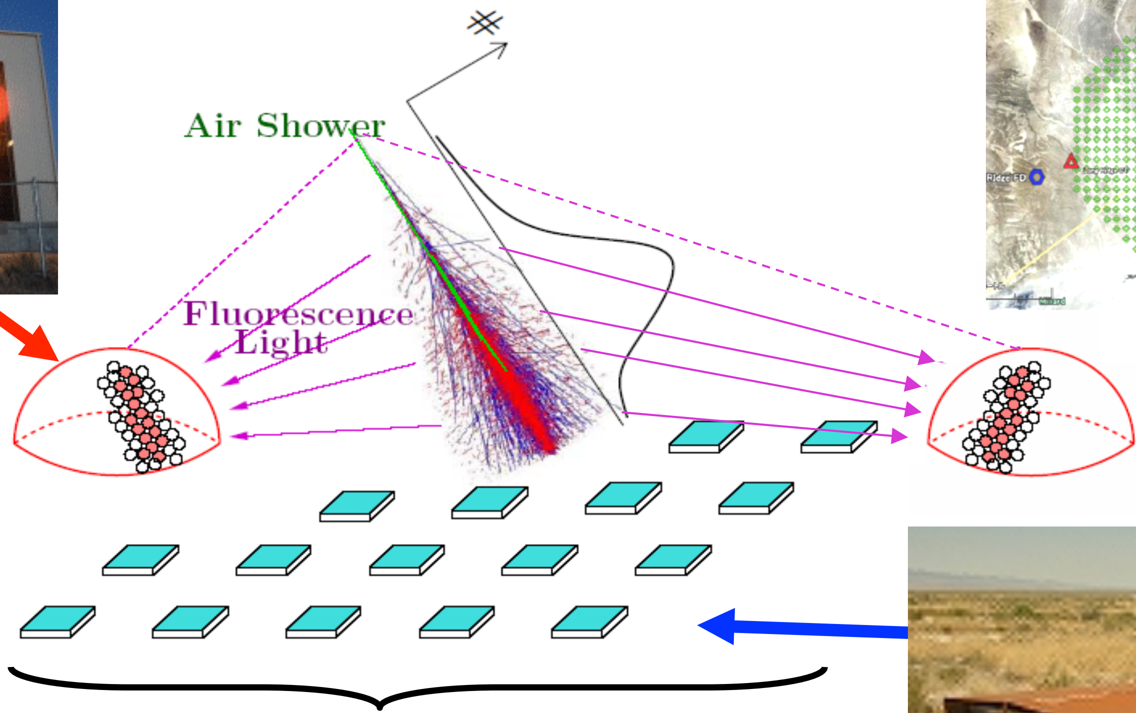
RIKEN

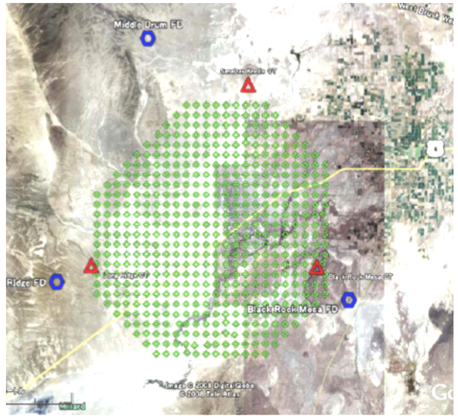
Telescope Array(TA) Experiment

Hybrid observation: SD (507 units) + FD (3 locations: 38 units)

Fluorescence Detector (FD)





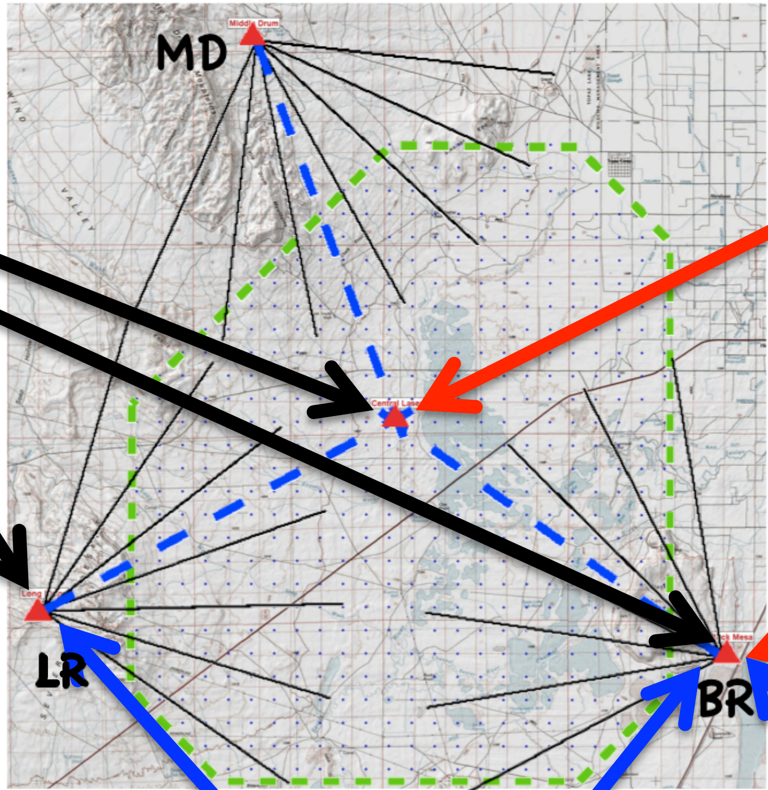


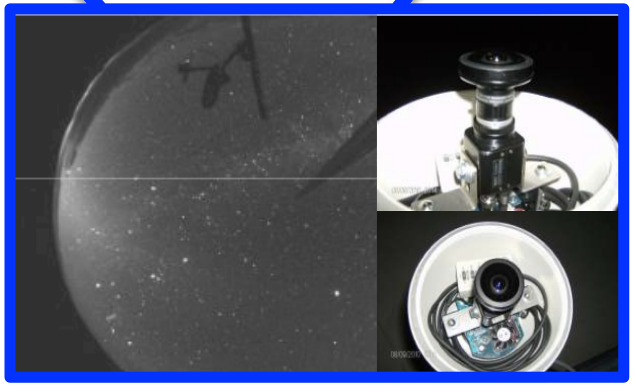
Surface Detectors SDs

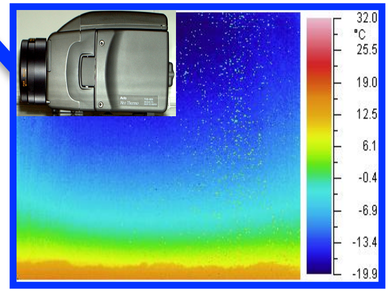
Plastic scintillator

The joint experiment with Japan, the United States , South Korea, Belugium and Russia. The observation started in Apr. 2008 North American at Utah

Atmospheric monitor in TA







- LIDAR
- CLF
- LIDAR@CLF
- IR camera
- CCD camera
- weather monitor

Contents

- **LIDAR observation**

The atmospheric transparency model of two kinds of altitude distribution was determined.

- **Influence of using LIDAR's atmospheric transparency for FD reconstruction.**

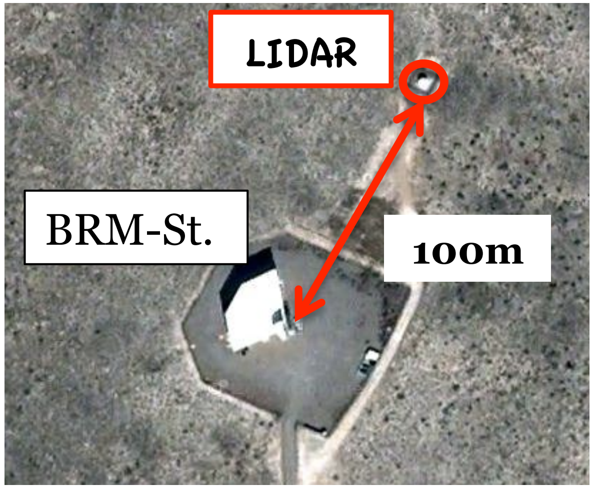
FD reconstruct fluctuation was estimated by using the atmospheric model.

- **CLF Observation**

Correlated to the time variations was observed when compared to the CLF and LIDAR by Optical Depth.

- **IR camera Observation**
- **Eye-scan**

LIDAR System



BRM Station

Telescope & dome of TA LIDAR

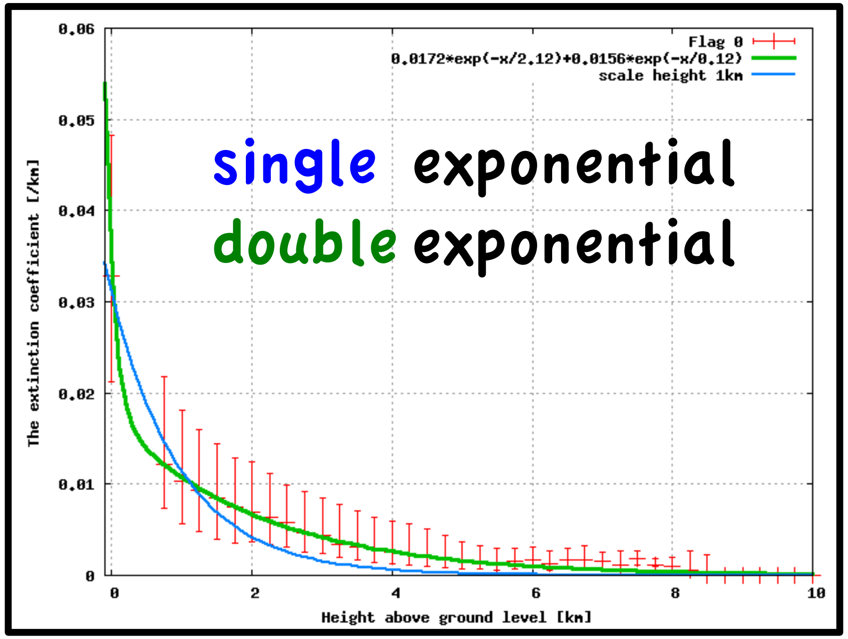
Measurement : Before and After FD observation

Slope	Horisontal shots - high power - 500 shots	$\alpha_M(h=0km)$
Klett's	Vertical shots - high/low power - 500 shots	$\alpha_M(h=2\sim 8km)$
	Incline shots - high power - 500 shots	$\alpha_M(h=0.5\sim 4km)$

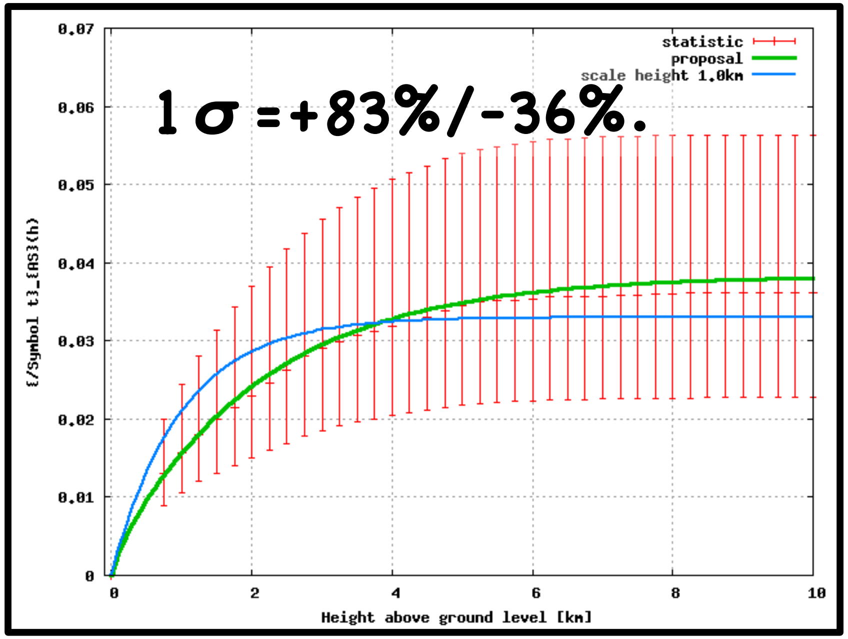
Data condition for determination atmospheric model

Data period	**~2 year (Sep.2007 ~ Oct.2009)**	
Using data	**Fine data**	**✓Good LIDAR observation** **✓Transparent atmosphere**
Rayleigh	**Radiosonde atmosphere @ELKO**	

Models of Atmospheric transparency



Extinction coefficient at each height



VAOD at each height

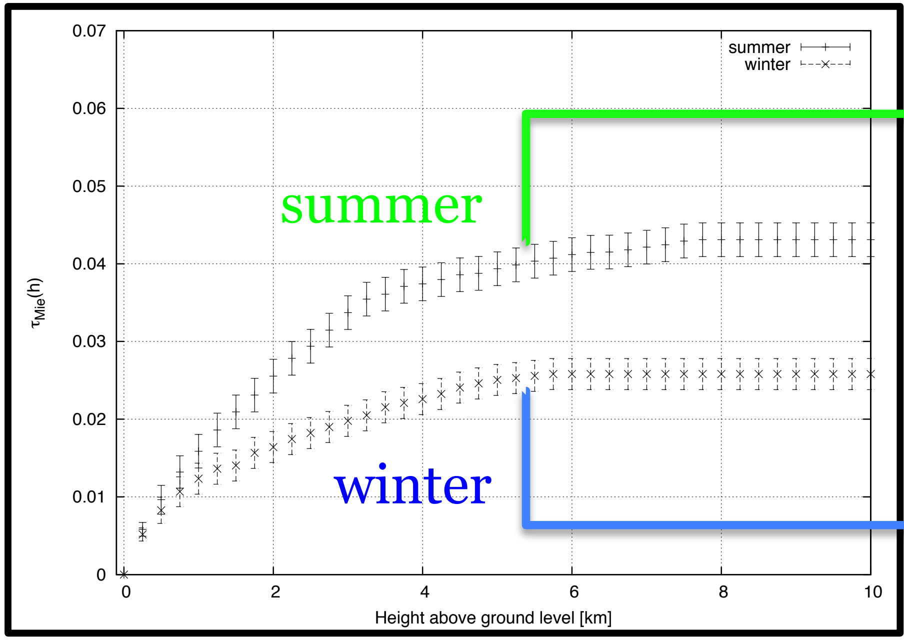
Double exponential Model

$$\alpha_{AS} = 0.019 \times \exp(-h/0.19) + 0.021 \times \exp(-h/2.1)$$

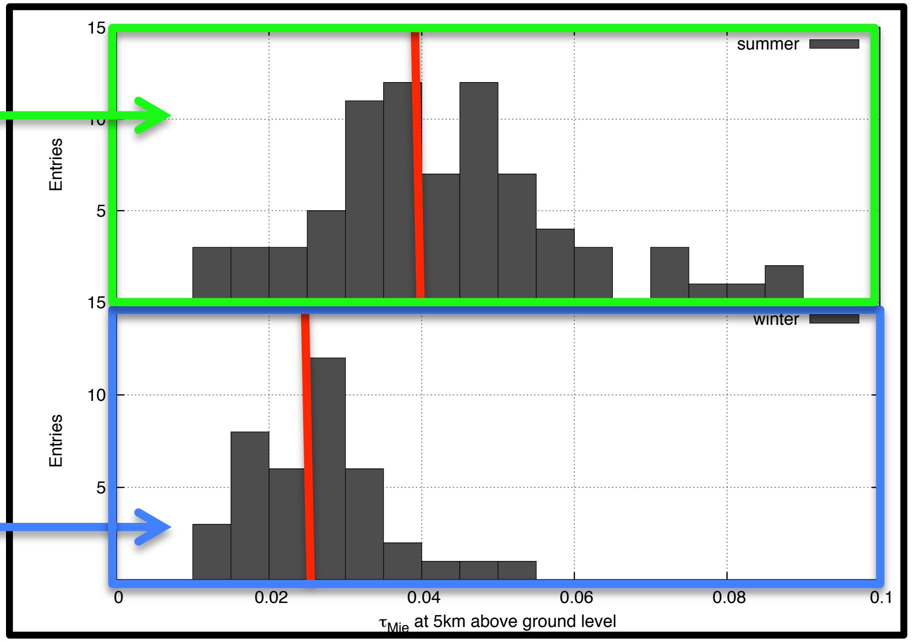
Single exponential Model

$$\alpha'_{AS} = 0.039 \times \exp(-h/1.0)$$

Seasonally Aerosol scattering



Median of VAOD for different seasons



Distribution of VAOD at 5km above ground level for different seasons

Summer: **$0.039^{+0.020}_{-0.012}$**

Winter : **$0.025^{+0.010}_{-0.007}$**

The effect of the aerosol component in summer is 1.5 times greater than that in winter.

Fluctuation of FD reconstruction using atmospheric transparency by the LIDAR measurement.

=Method=

- MC simulation using daily atmospheric transparency to create a shower data.
- Simulated data are reconstructed using daily atmospheric transparency or model function.
- Estimating the impact of using a model function to compare the results with the reconstruction of each atmospheric transparency.
- ΔE is evaluated by the ratio, ΔX_{Max} will be evaluated by difference.
- Reconstruction using **Daily** atmospheric data or two atmospheric **models**

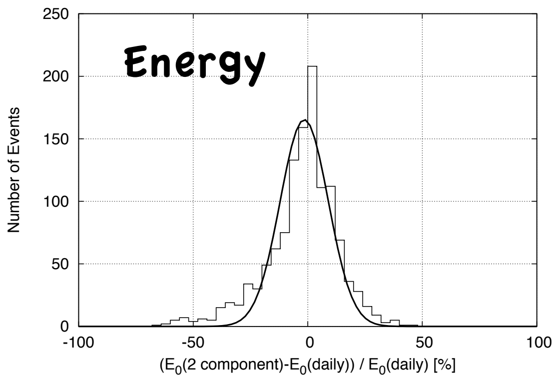
$$\frac{\Delta E}{E_{Daily}} = \frac{E_{Model} - E_{Daily}}{E_{Daily}} \qquad \Delta X\max = X\max_{Model} - X\max_{Daily}$$

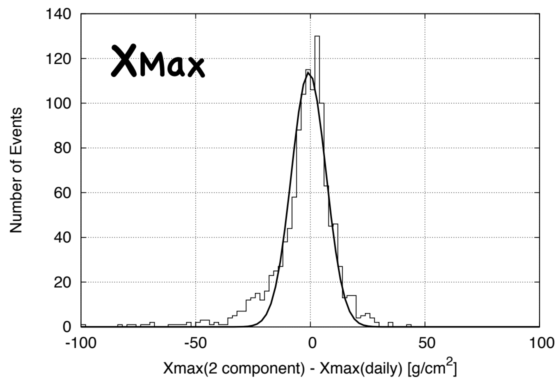
=Simulation conditions=

- Primary energy : logE= 18.5, 19.0 and 19.5 eV
- Direction: Zenith is between 0 ~ 60 ◦ (the isotropic)
  Azimuth is between 0 ~ 360 ◦ (the isotropic)
- Core position : within 25 km of the CLF (center of TA FDs).
- Number of event : 20 events at each energy for each of 136 good LIDAR runs.
- Quality Cuts : Reconstructed X_{max} in field of view of FD.

Fluctuations by using the atmospheric model

Daily vs model func. @logE=19.5 eV





$$\frac{\Delta E}{E_{Daily}} = \frac{E_{Model} - E_{Daily}}{E_{Daily}}$$

$$\Delta X\max = X\max_{Model} - X\max_{Daily}$$

Comparison of reconstructed fluctuation in atmospheric model.

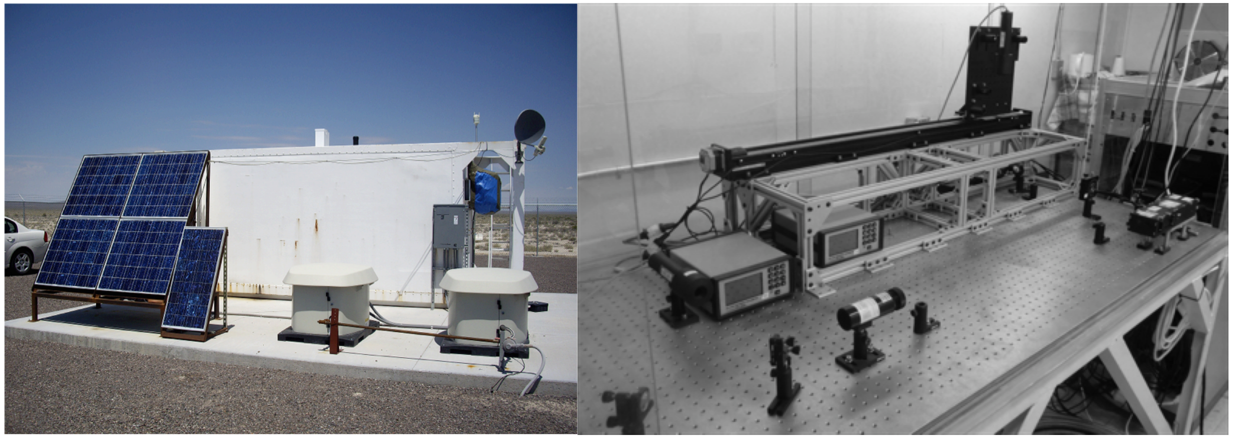
E_0[eV]	#eve.	Atmos.	ΔE_0[%]	ΔX_{Max}[g/cm^2]
$10^{18.5}$	501	1 exp.	1.7± 6.4	4.6±7.1
	502	2 exp.	-2.4±6.3	-3.6±8.8
$10^{19.0}$	917	1 exp.	1.3±8.6	4.5±7.7
	919	2 exp.	-4.2±8.6	-5.0±8.6
$10^{19.5}$	1200	1 exp.	1.4±11.1	4.9±9.3
	1210	2 exp.	-0.6±10.6	0.2±7.6

The fluctuation not containing the reconstruction bias using atmospheric model at each energy

Rec. ΔE : 6%@18.5
9%@19.0
11%@19.5

Rec. ΔXmax : 9g@18.5
9g@19.0
9g@19.5

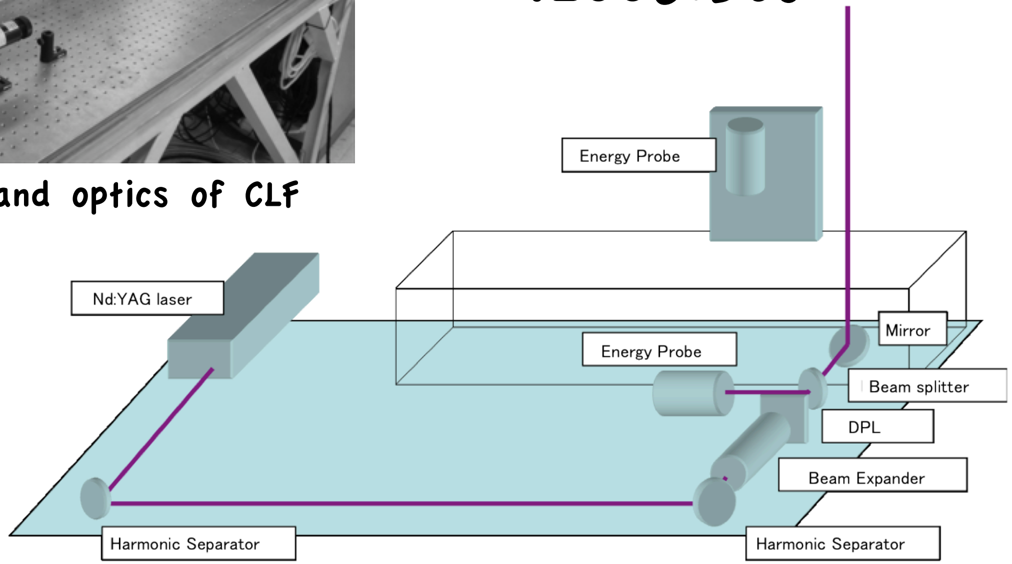
CLF System



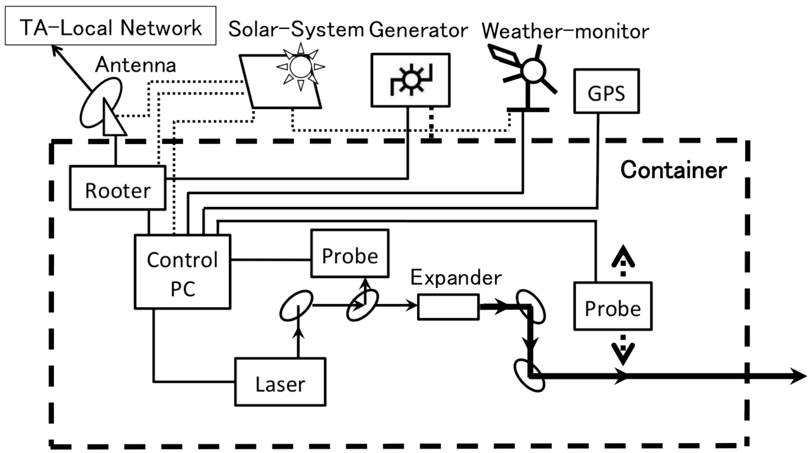
CLF container and power generation system and optics of CLF

Starting CLF operation

:2008.Dec～



Optical diagram of the CLF



Block diagram of devices for CLF

CLF laser is injected into FD's FOV

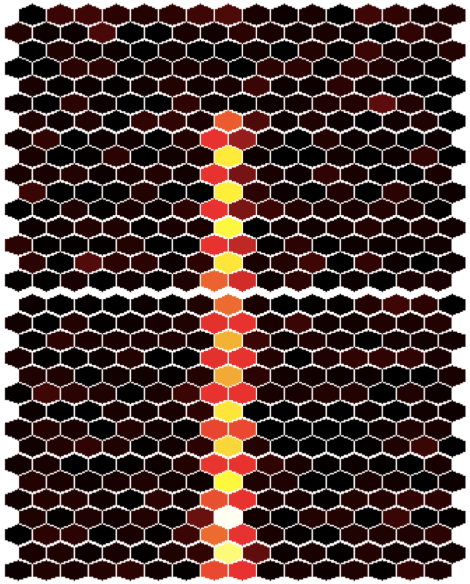
:300 shots

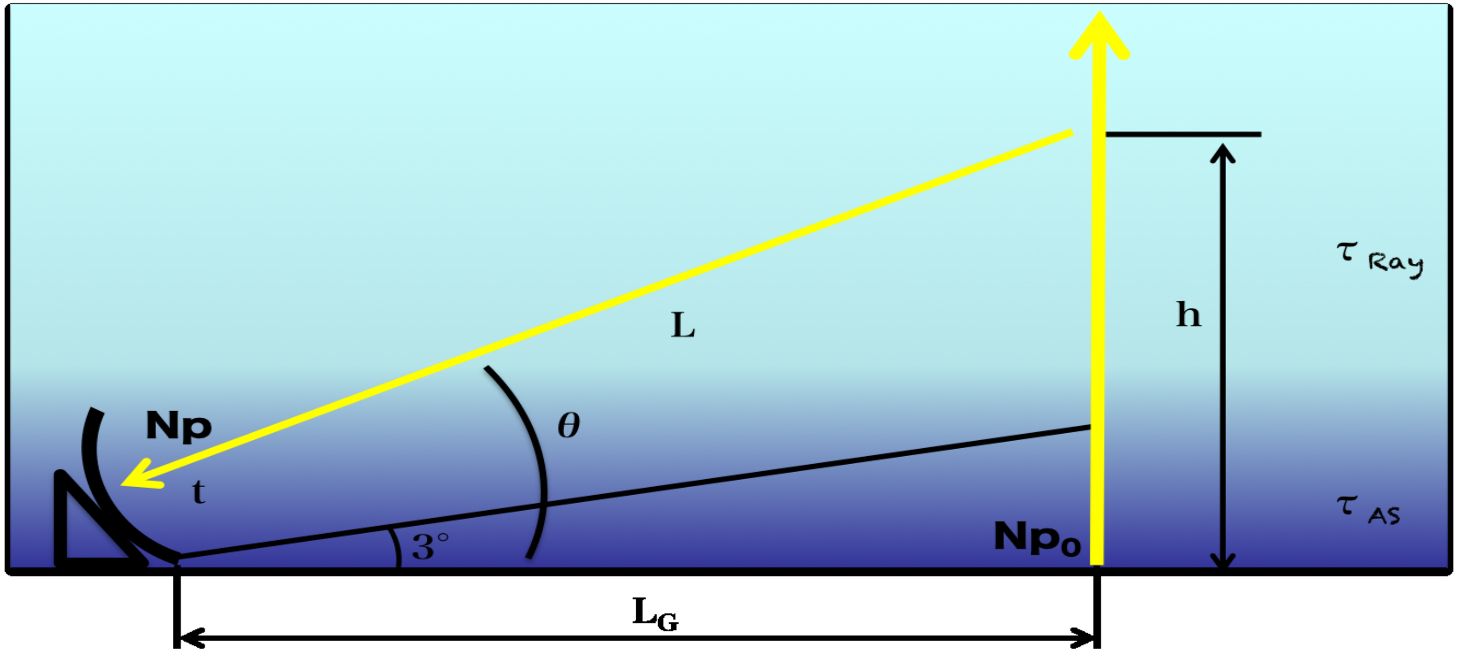
:10Hz

:vertical direction

:every 30 minutes.

CLF's observation image





VAOD eq.

$$Np = Np_0 Cf_{(\phi)} e^{-(\alpha_M + \alpha_A)(L_1 + L_2)} \Big/ L_2^{\ 2}$$

$$\begin{cases} T_{ij} = e^{-\tau_i / \sin\theta_j} \equiv e^{-\alpha_i L_j} \\ L_j = h / \sin\theta_j, \tau_i \equiv \alpha_i h \end{cases}$$

$$Np = Np_0 T_{Ray} T_{AS} (S_{Ray} + S_{AS}) T'_{Ray} T'_{AS}$$

analysis method

$$\begin{cases} Np = Np_0 T_{Ray} T_{AS} (S_{Ray} + S_{AS}) T'_{Ray} T'_{AS} \\ Np_{Ray} = Np_{i0} T_{Ray} S_{Ray} T'_{Ray} \end{cases}$$

$$\exp\left(-(\alpha_{Ray} + \alpha_{AS})\Delta h\right)\left(\frac{\sigma_{Ray}\alpha_{Ray} + \sigma_{AS}\alpha_{AS}}{\alpha_{Ray} + \alpha_{AS}}\right)$$

$$Np \big/ Np_{Ray} = \frac{E}{E_i} T_{AS} T'_{AS} \left(1 + S_{AS} \big/ S_{Ray}\right)$$

Uniform atmospheric

$$T = \exp\left(-\tau(h)\right)$$

$$T' = \exp\left(-\tau(h)/\sin\theta\right)$$

$$Np \big/ Np_{Ray} = \frac{E}{E_i} \exp\left(-\frac{1+\sin\theta}{\sin\theta}\tau_{AS}(h)\right)\left(1 + S_{AS} \big/ S_{Ray}\right)$$

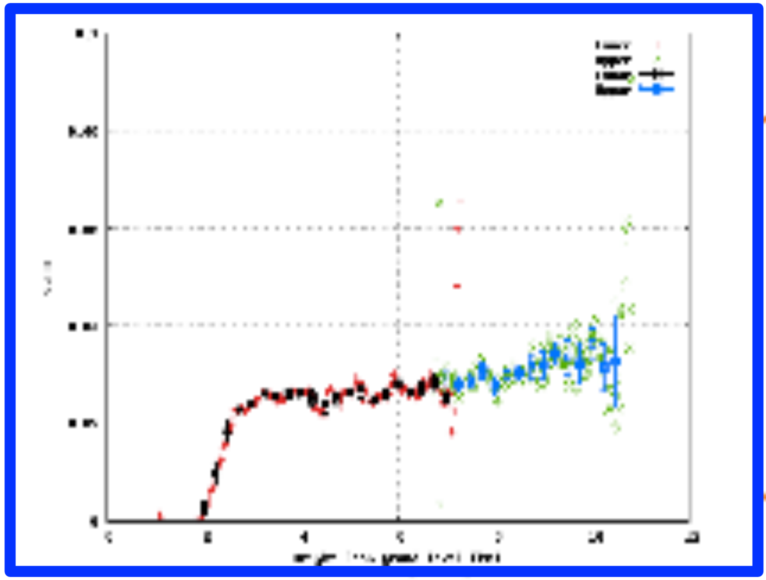
No aerosols

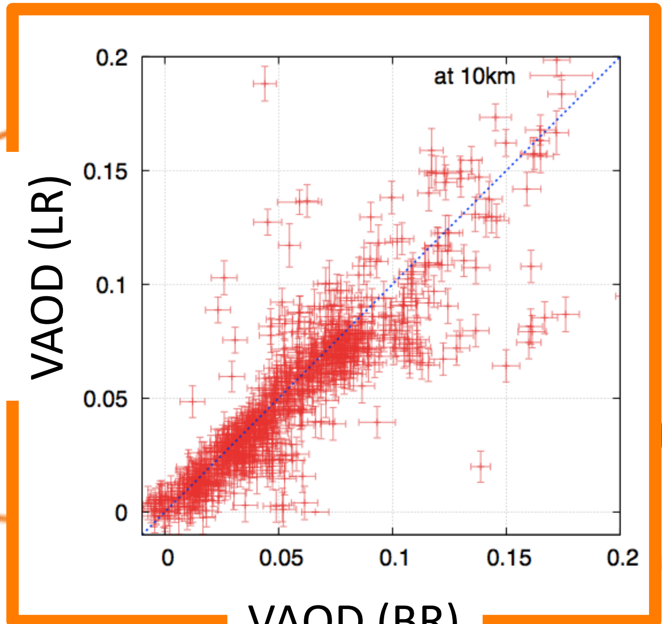
$$h > 7km$$

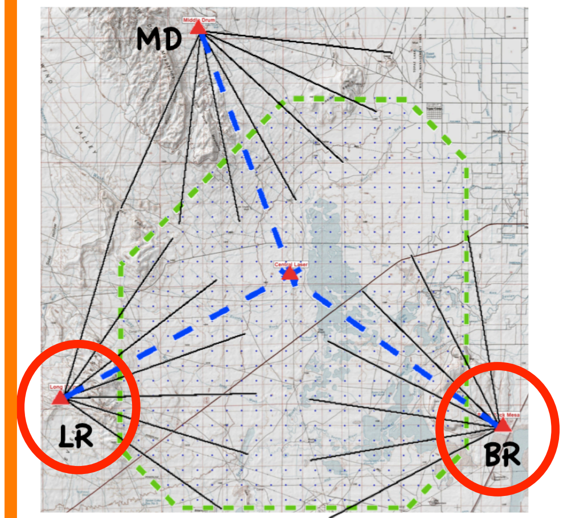
$$\alpha_{AS} = 0[km^{-1}]$$

$$\frac{\frac{Np}{E}}{\frac{Np_{Ray}}{E_i}} = \exp\left(-\frac{1+\sin\theta}{\sin\theta}\tau_{AS}(h)\right)$$

VAOD (Example) & Comparison of BR &LR







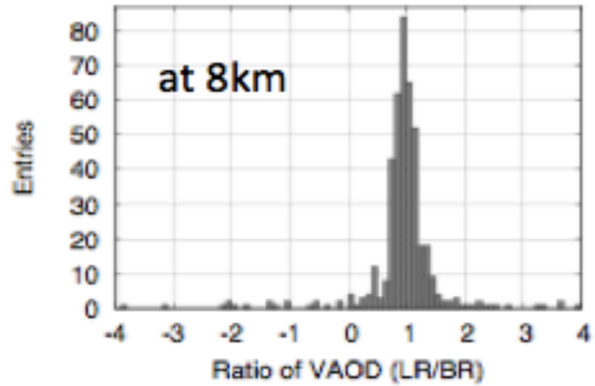
The Ratio of BRM and LR every-observation

@ 8km

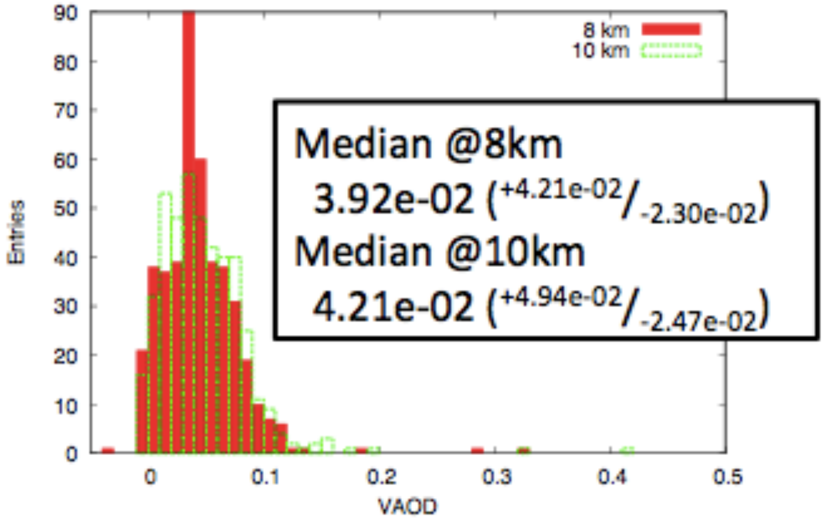
BRM:LR = 1.000 : 0.963

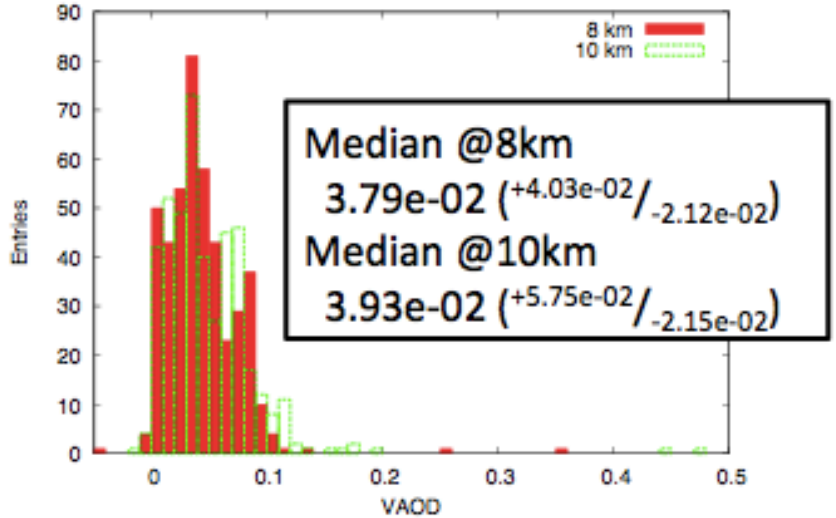
@10km

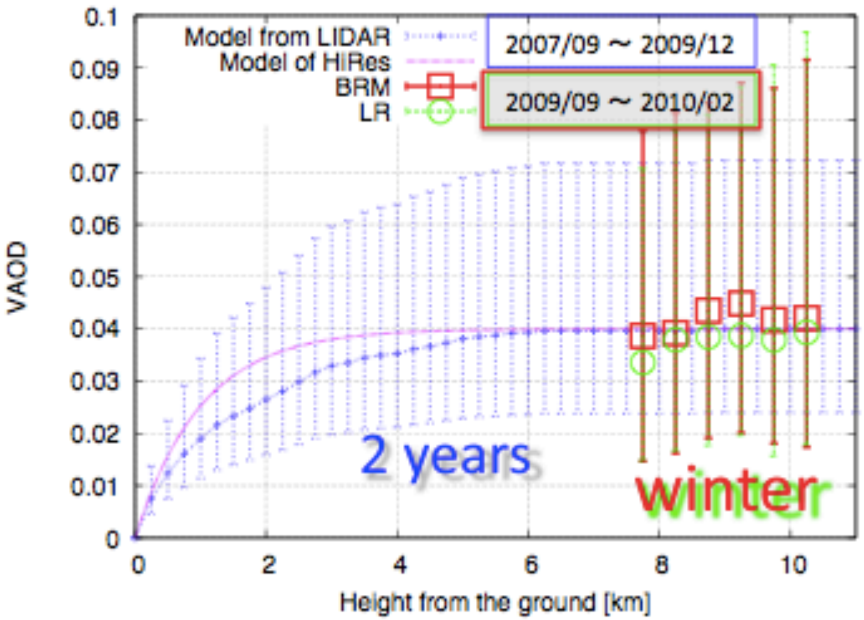
BRM:LR = 1.000 : 1.004



Comparison of BRM and LR (Median)







BRM / LR = 1.11

$$\frac{(VAOD_{BRM} - VAOD_{LR})/2}{(VAOD_{BRM} + VAOD_{LR})/2} = 0.05$$

Conclusion of LIDAR

- The extinction coefficient α is obtained from LIDAR observation, then the VAOD $\tau_{AS}(h)$ is defined as the integration of α from the ground to height h.
- A model of α_{AS} with altitude was found by fitting two years of LIDAR observations.
- The range of variation of the daily data from the model is +83%/-36%.
- When $10^{19.5}$ eV air shower is reconstructed using the model function, the systematic uncertainty of energy is shown to be about 11%.
- And the systematic uncertainty of X_{Max} to be about 9 g/cm^2 by comparing MC simulation data.

Conclusion of CLF

- VAOD was analyzed by using the CLF event of high view camera's.
- BR and LR are consistent with a few %.
- There is a correlation VAOD measured in each of the CLF and LIDAR.
- Using the CLF, will be able to interpolate for the atmospheric transparency of the period where have not been observed by LIDAR.

LIDAR@CLF system

Hardware (general drawing)

- Back-scatter detector is set up on top of the CLF.
- LIDAR@CLF use PMT of 20mm and 38mm in diameter.
- telescope & 20mm PMT for High altitude (1.5~7.0~ km)
- 38mm PMT for Low altitude (~2.5km)

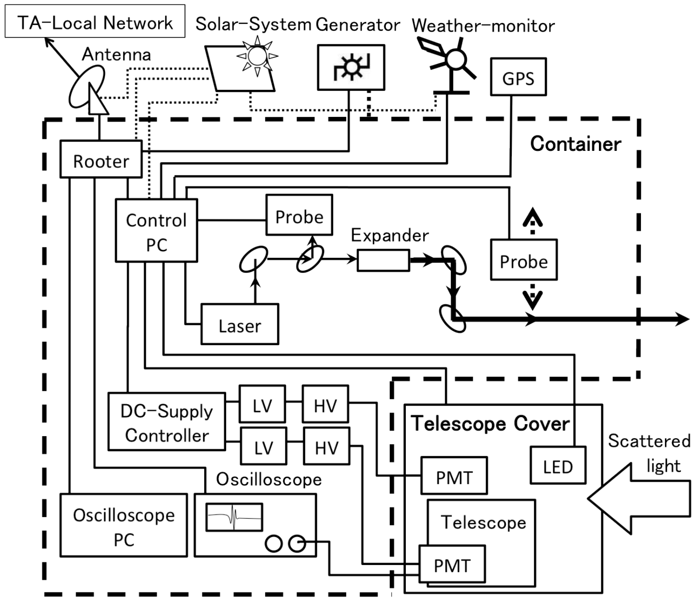


Fig. Block diagram of LIDAR@CLF

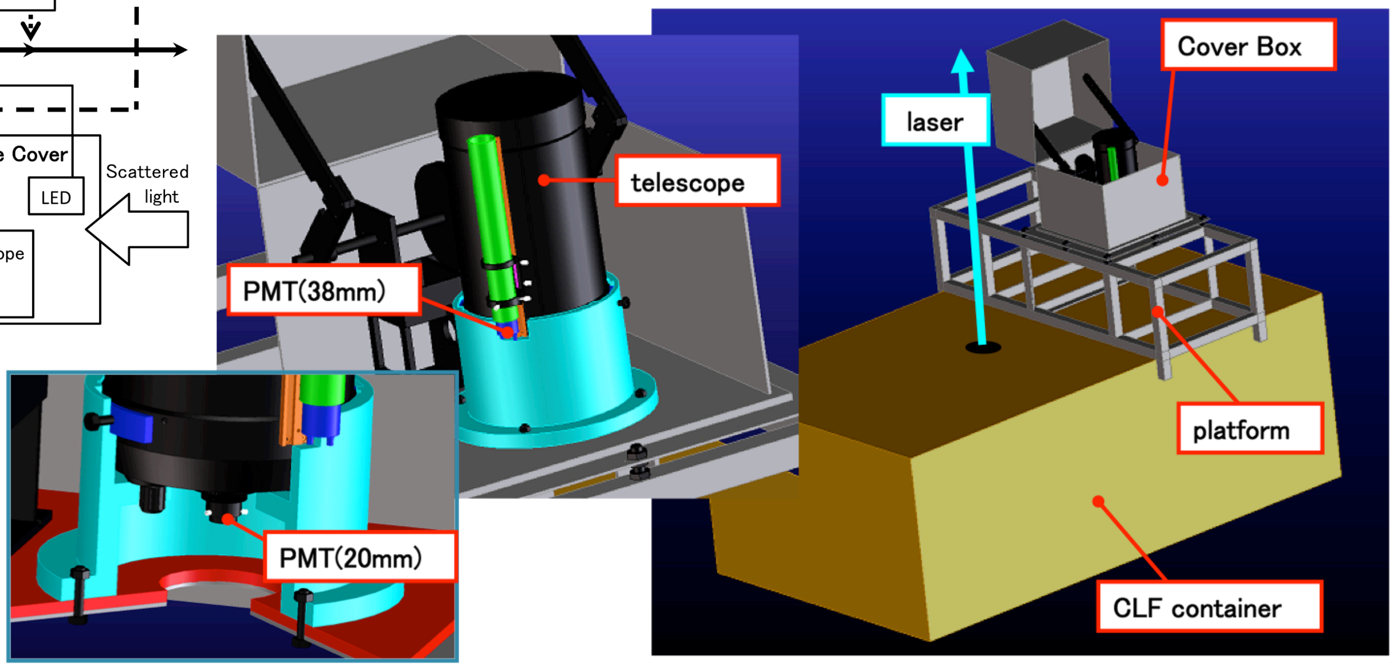
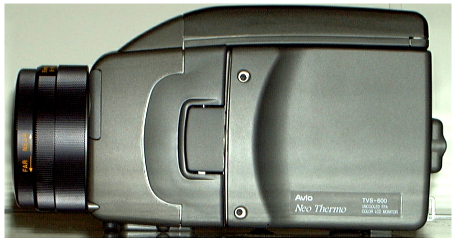


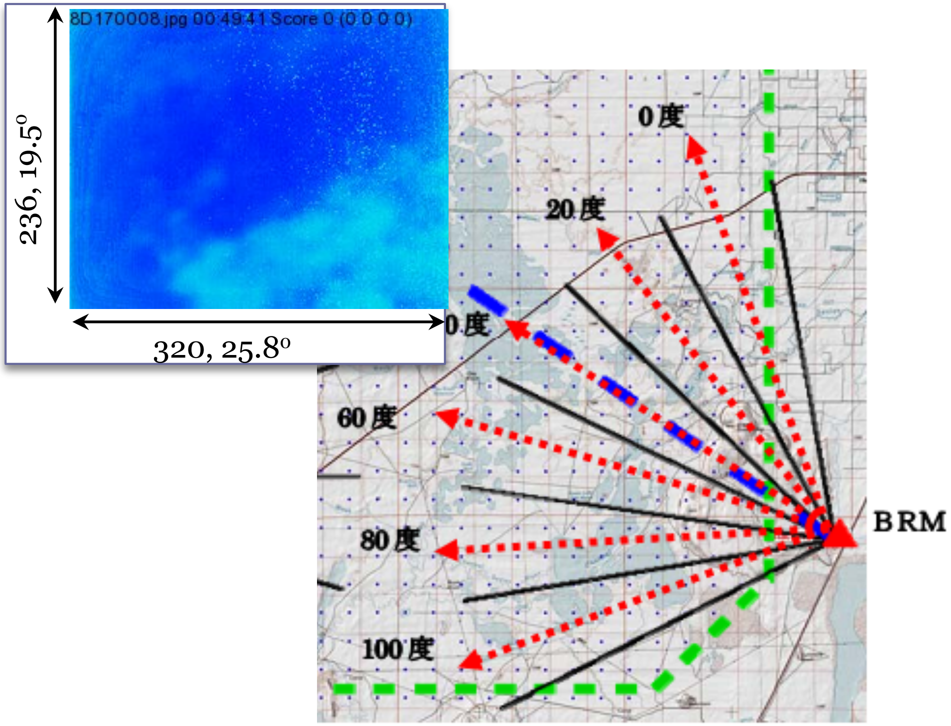
Fig. general drawing of LIDAR@CLF

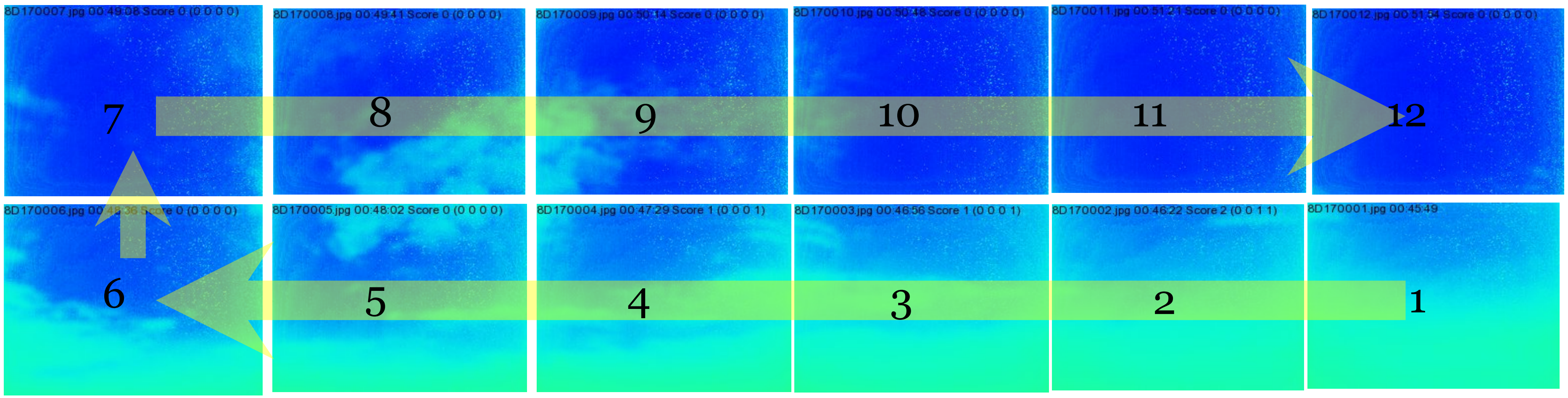
Cloud monitor

TA IR camera

- Sensitive 8 ~ 14 us
- 320 x 236 pixels
- FOV: 25.8° x 19.5°
- Near the LIDAR dome
- Once every 50 min (~2009Jul)
  or 30min (2009Jul~)

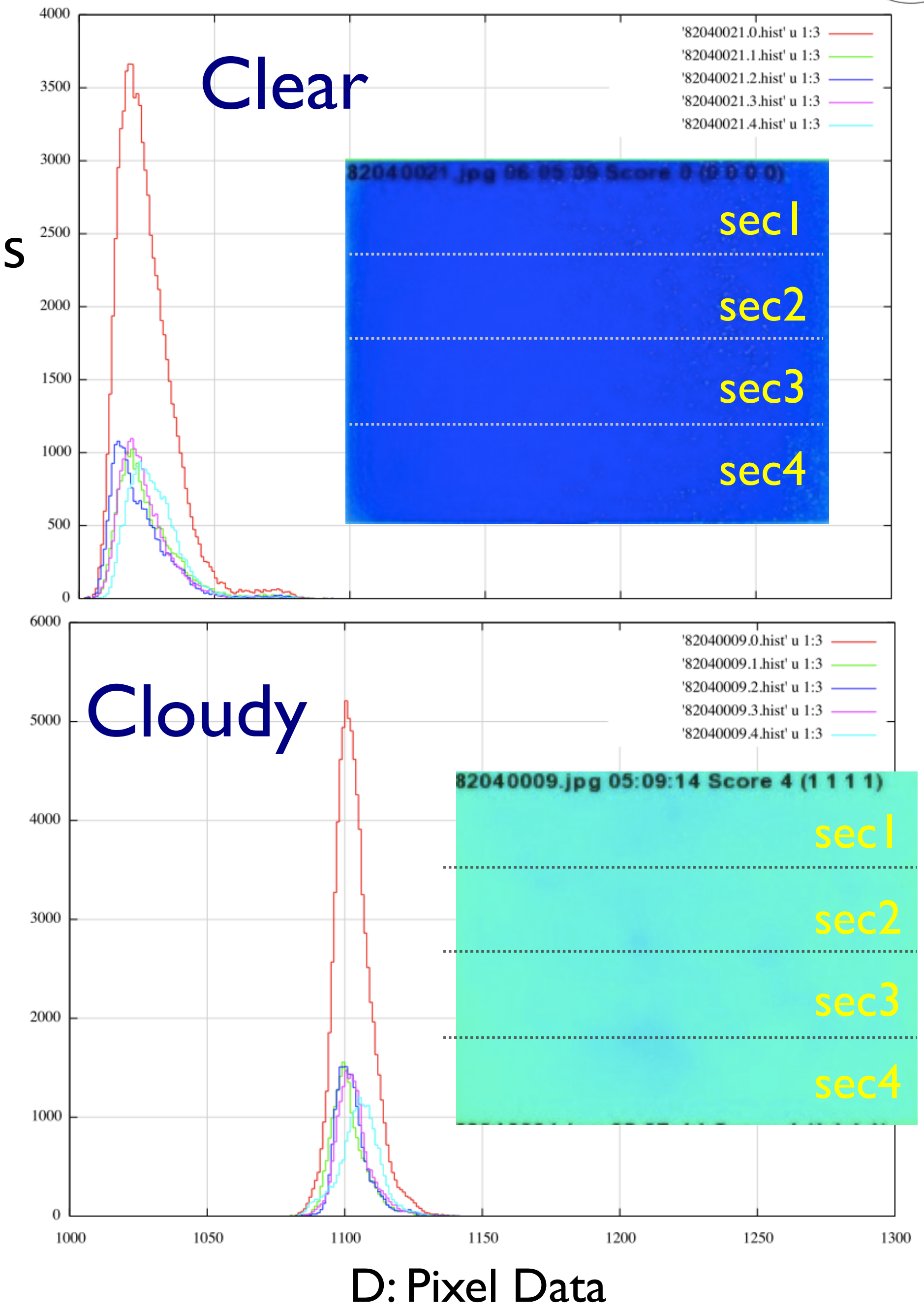




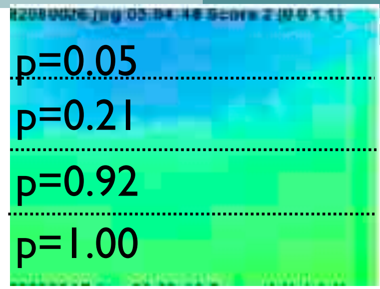


IR Sky Images

1. If there are clouds, the sky looks warmer.
2. An IR image are split into 4 "sections" horizontally in data analysis, because lower elevation region looks like warmer.
3. Deciding the probability of cloud in each section and each season.



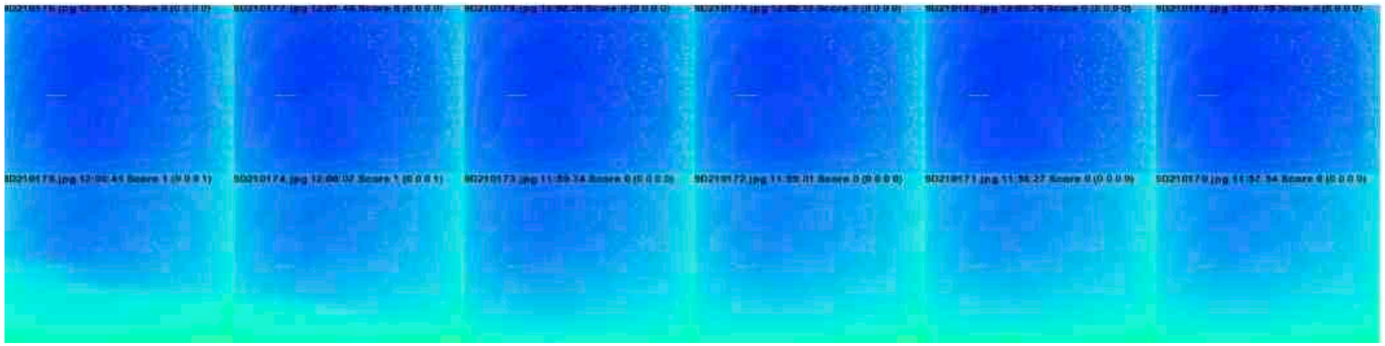
Examples



Score = 2.18/4.00

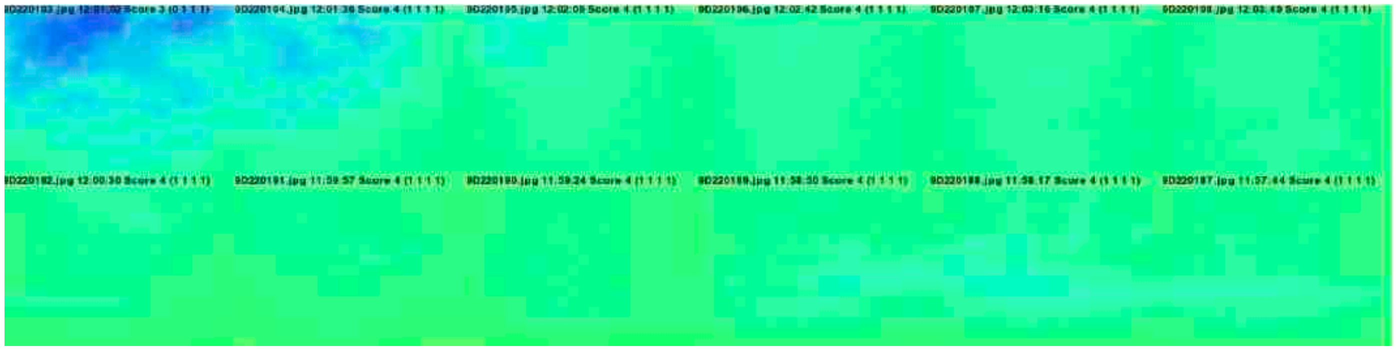
Total: 1.05/48.0

Clear night



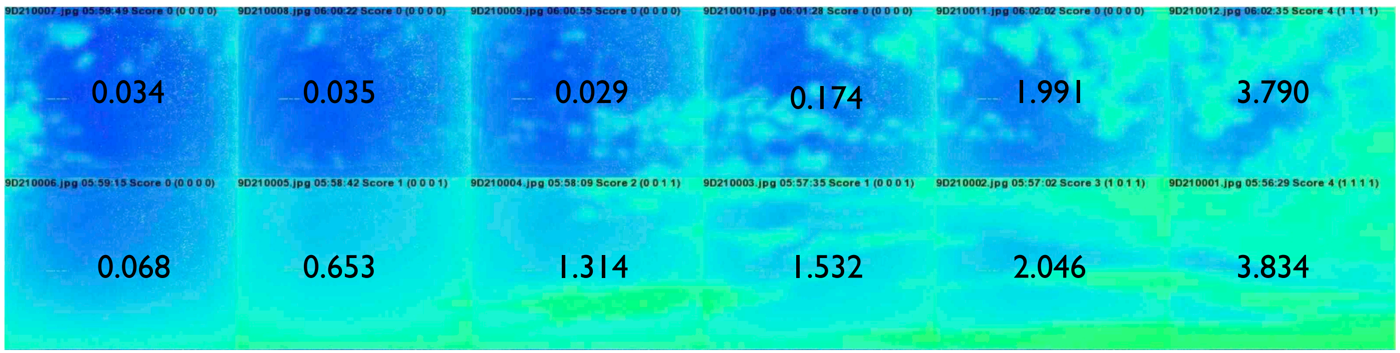
Total: 47.0/48.0

Cloudy night

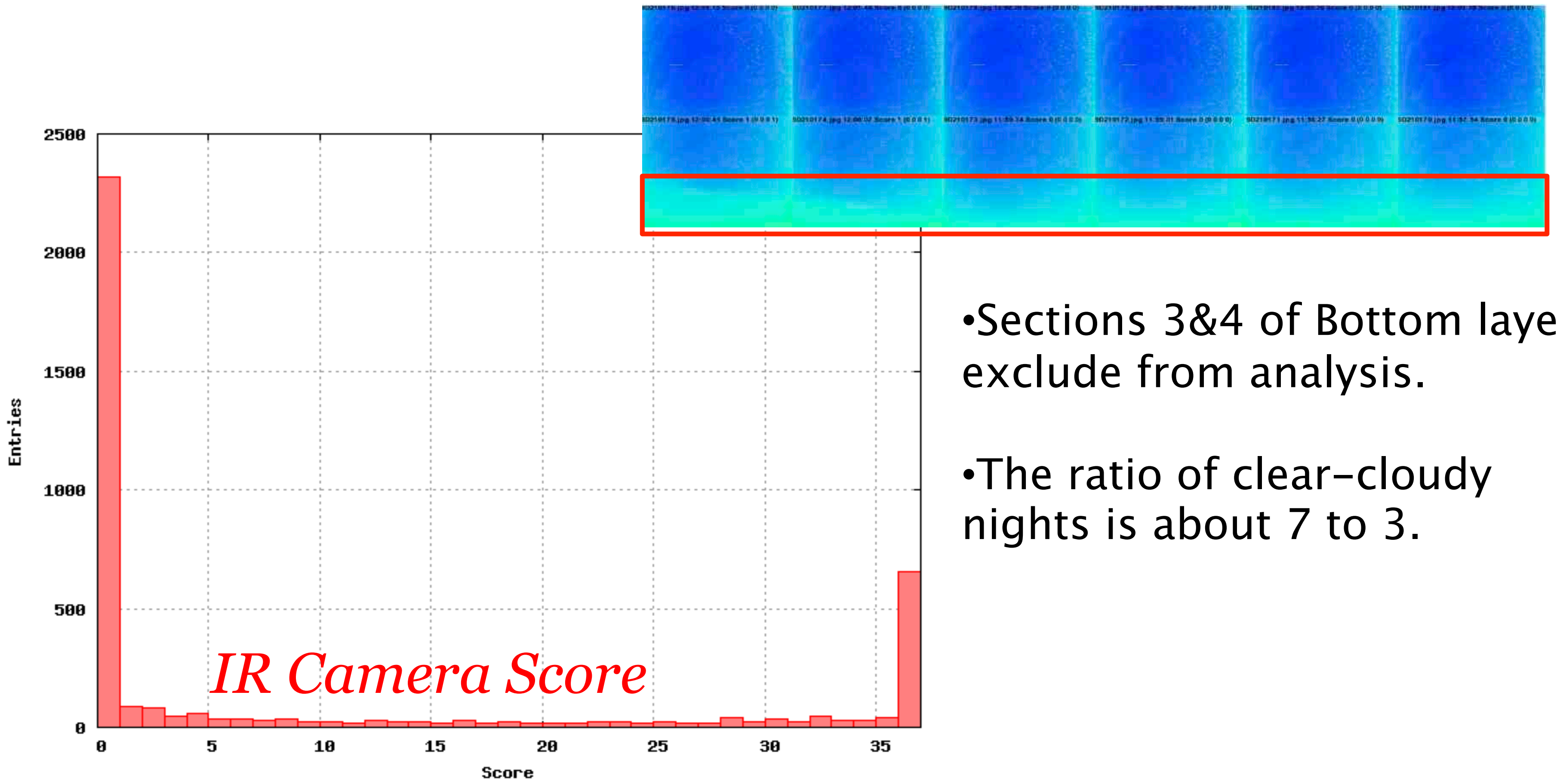


Total: 13.0/48.0

Sparse night



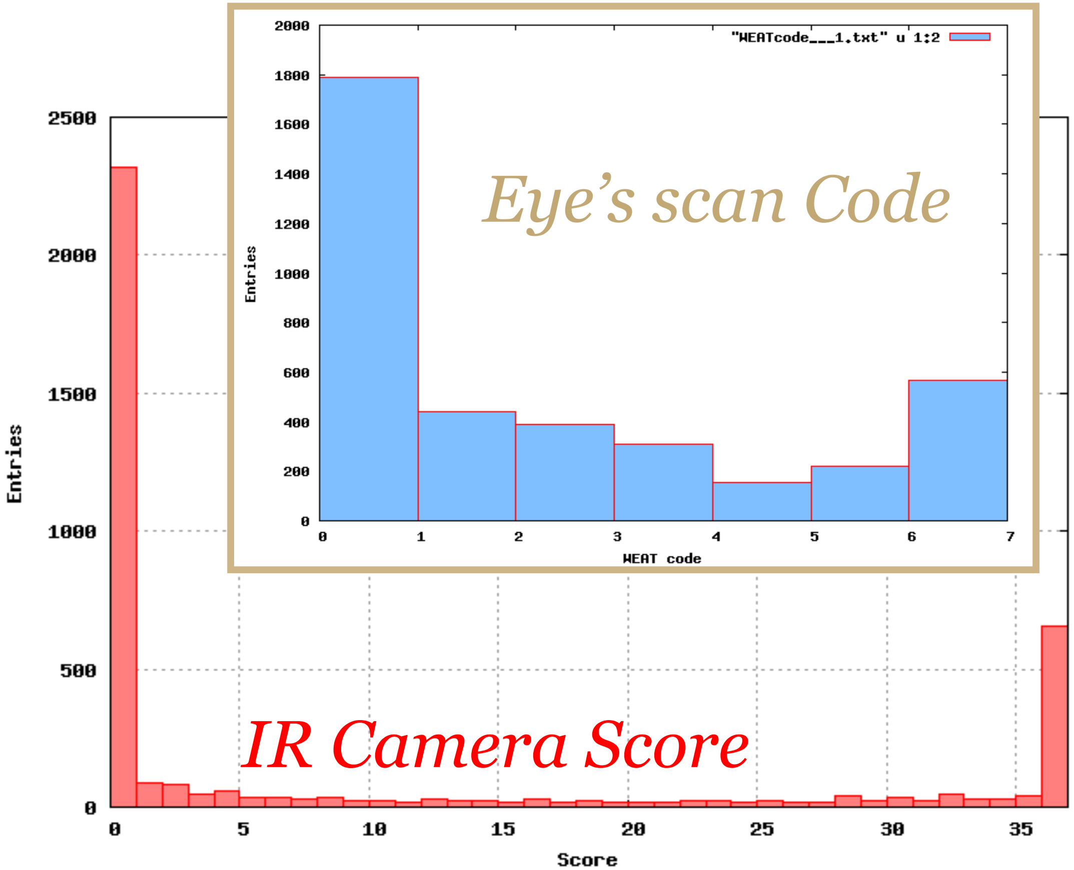
Sum of Scores of All the Directions



Clear **Cloudy**

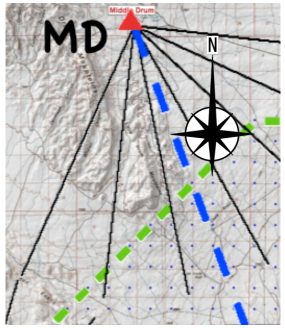
- Sections 3&4 of Bottom layer exclude from analysis.
- The ratio of clear-cloudy nights is about 7 to 3.

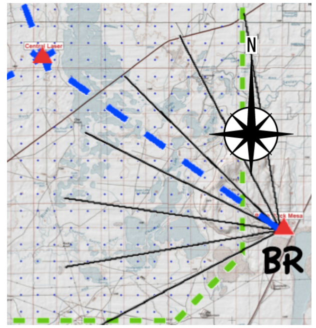
Comparison between IR and Eye-scan



Clear

Cloudy



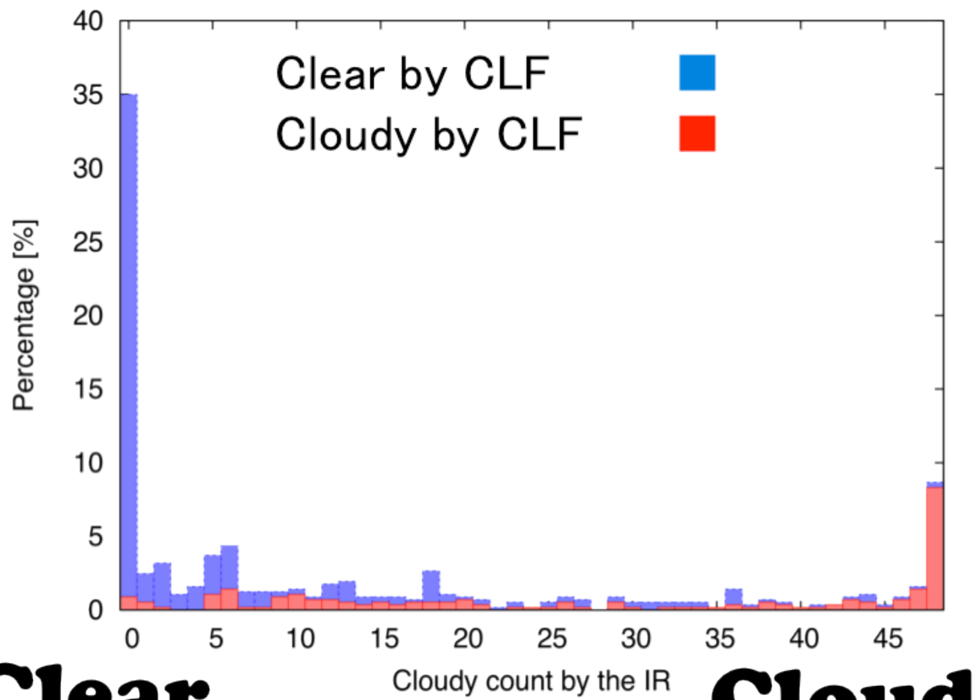


- Eye's-Scan Code is index of the cloud to determine in the observer's eye to the FD observation night.

- The code is a total of 6 points.

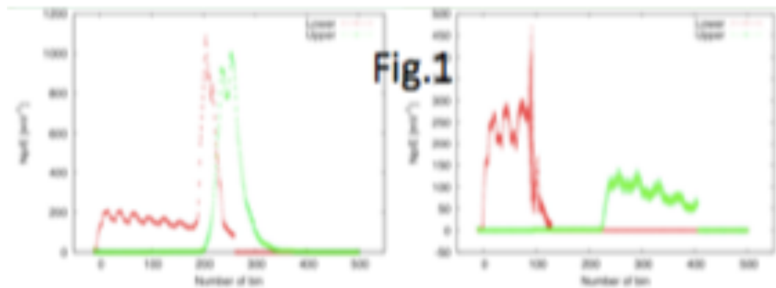
- IR score and Eye-scan code is consistent.

Comparison between IR and CLF



Clear **Cloudy**

- The data is extracted, when CLF and IR operate within 10 minutes
- Color-coded a histogram of the IR score by CLF's weather condition.
- IR score and CLF data is consistent.



Examples are determined to cloudy in CLF

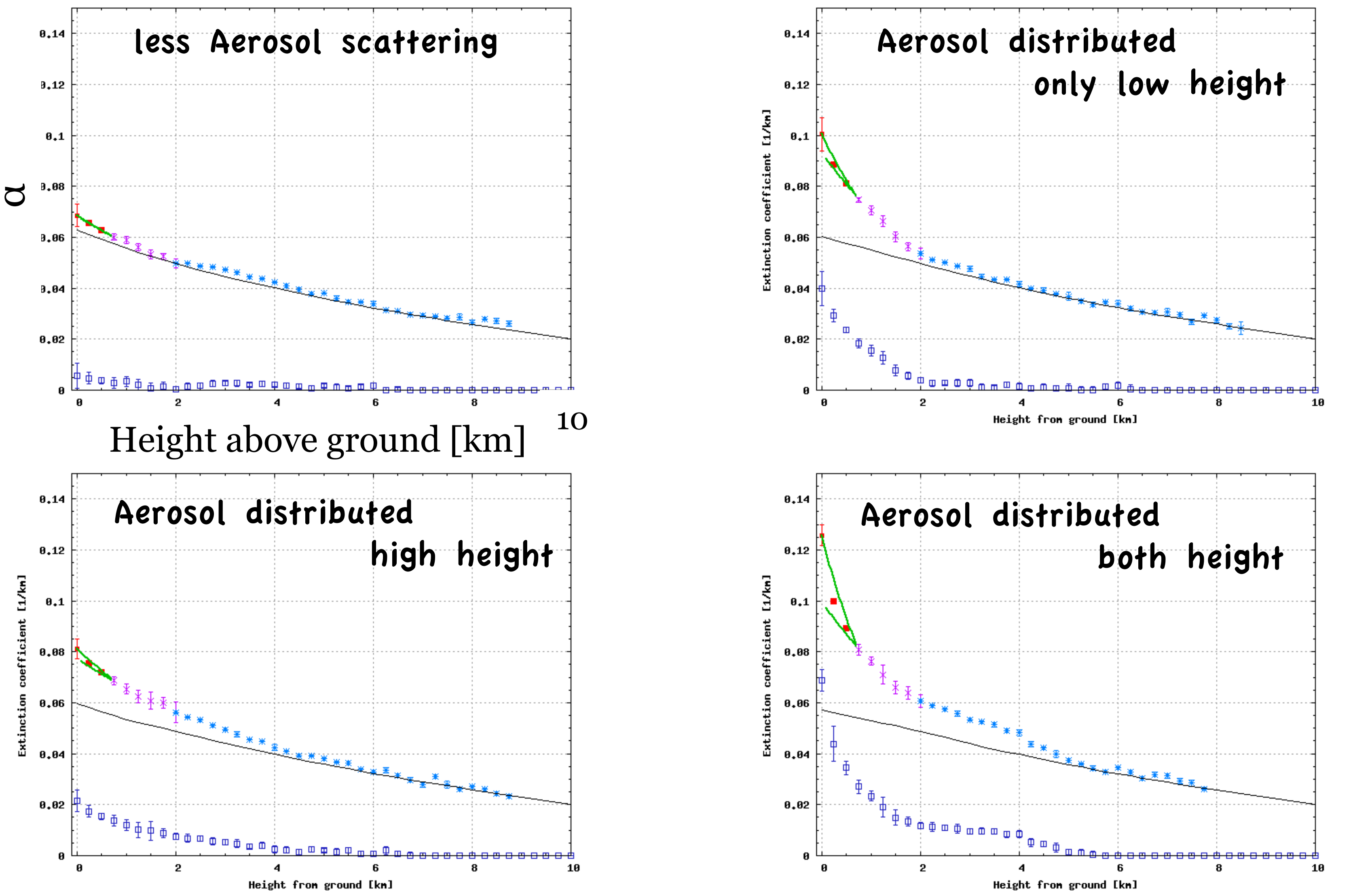
Conclusions (Cloud monitor)

- About 70% of the TA observation night is Clear night
- IR score and Eye-scan code is consistent.
- IR score and CLF data is consistent.

Typicals of Extinction Coefficient

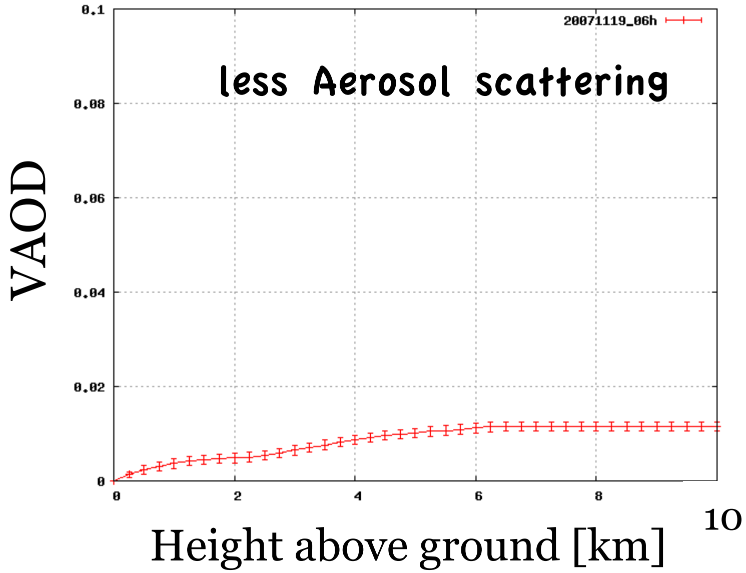
$$Np = Np_0 \exp(-\alpha x)$$

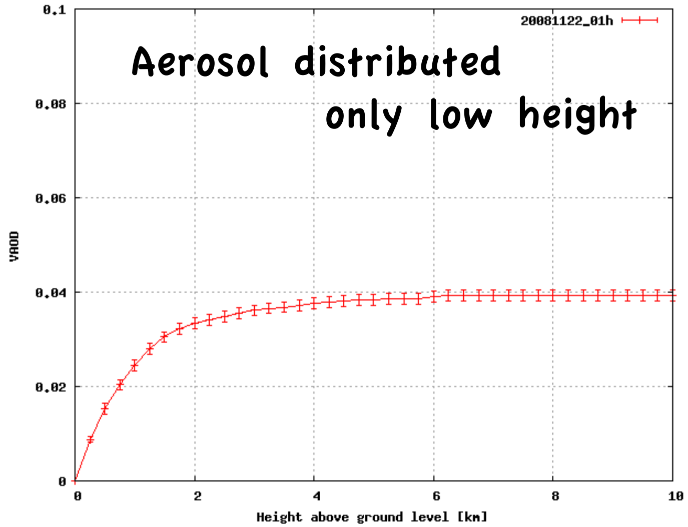
$$\alpha_{AS} = \alpha_{obs} - \alpha_{Rayleigh}$$

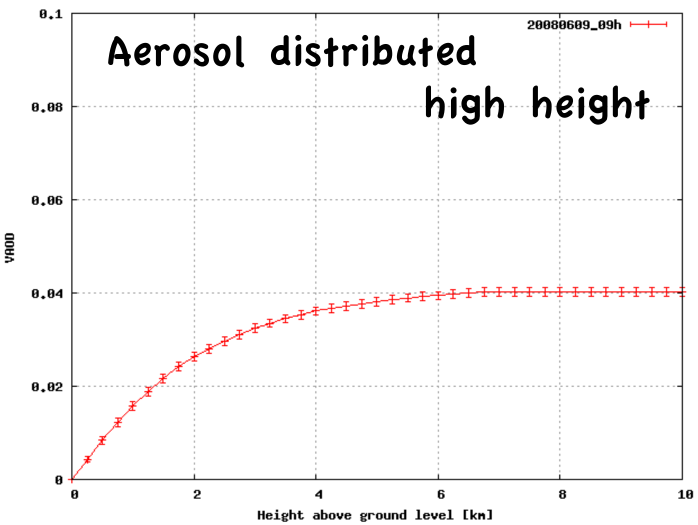


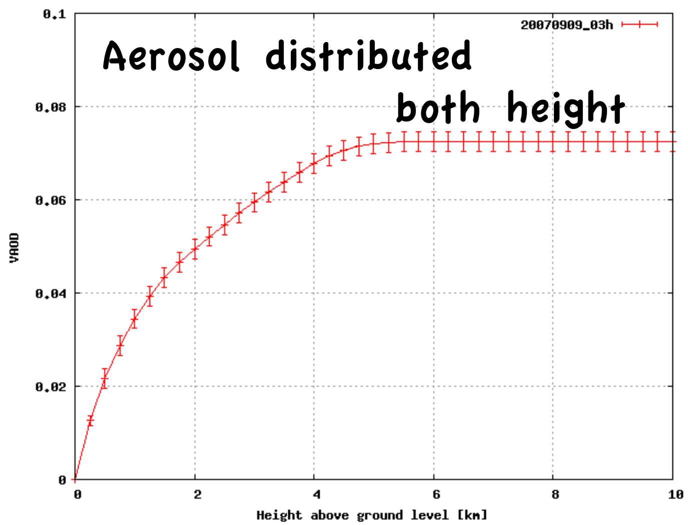
Typicals of VAOD

$$\alpha_{AS} = \alpha_{obs} - \alpha_{Rayleigh} \rightarrow VAOD(h) = \int_0^h \alpha_{AS}(h)dh$$

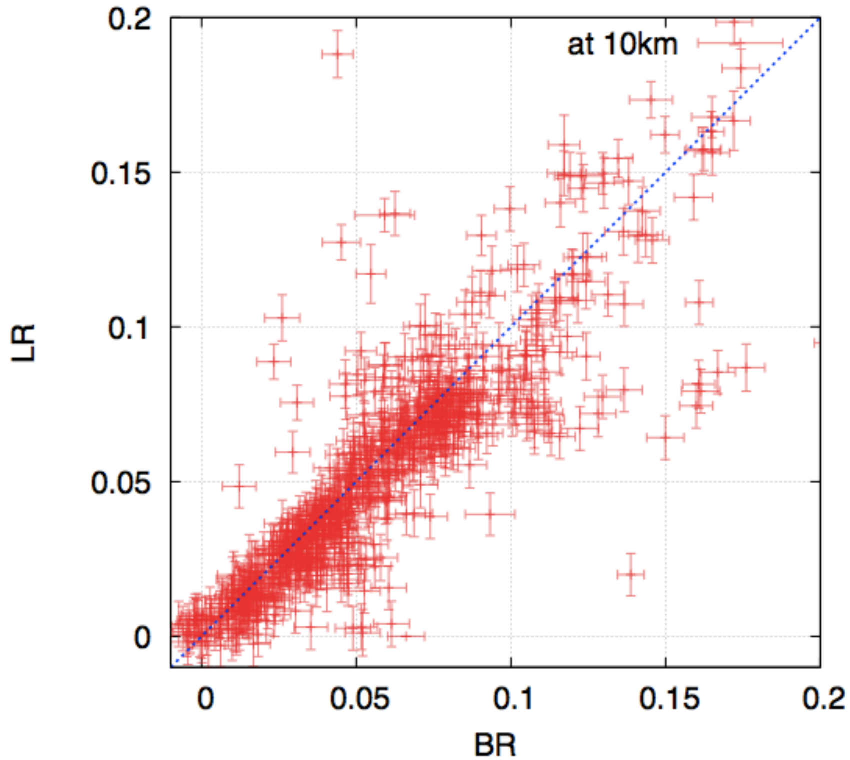


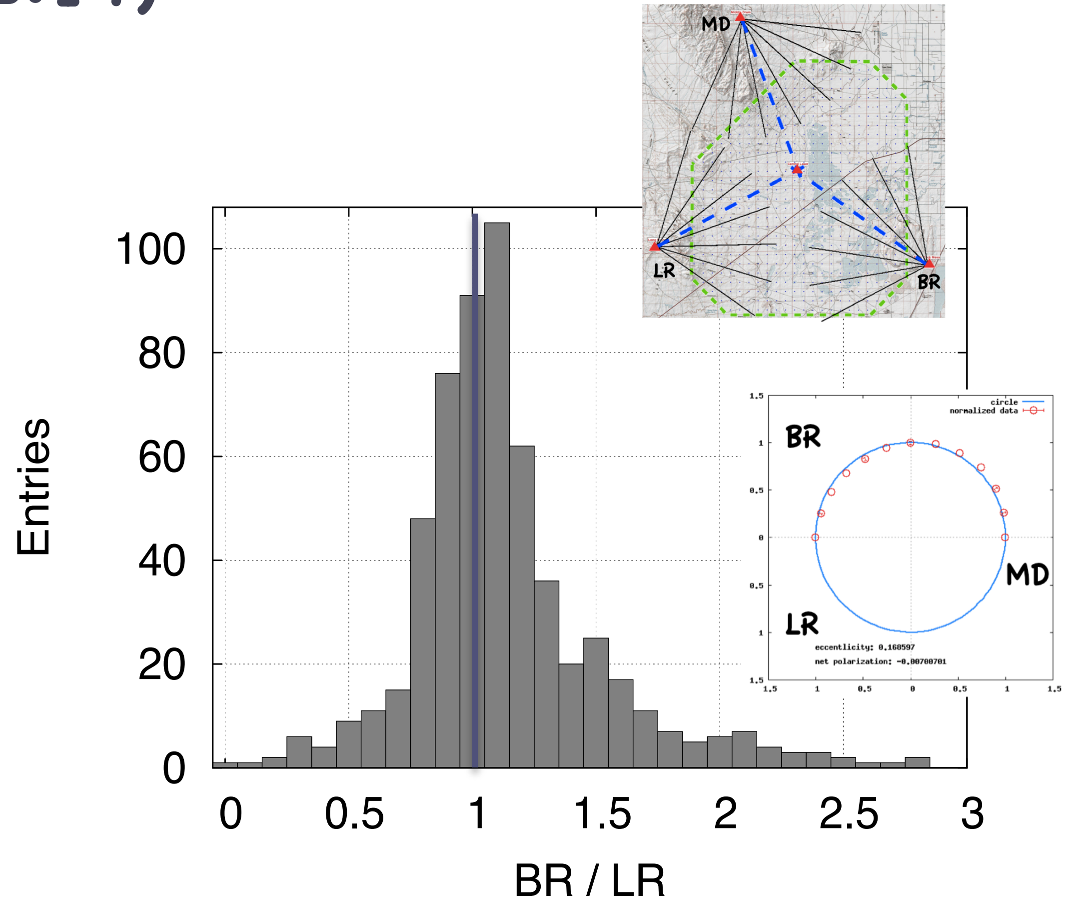






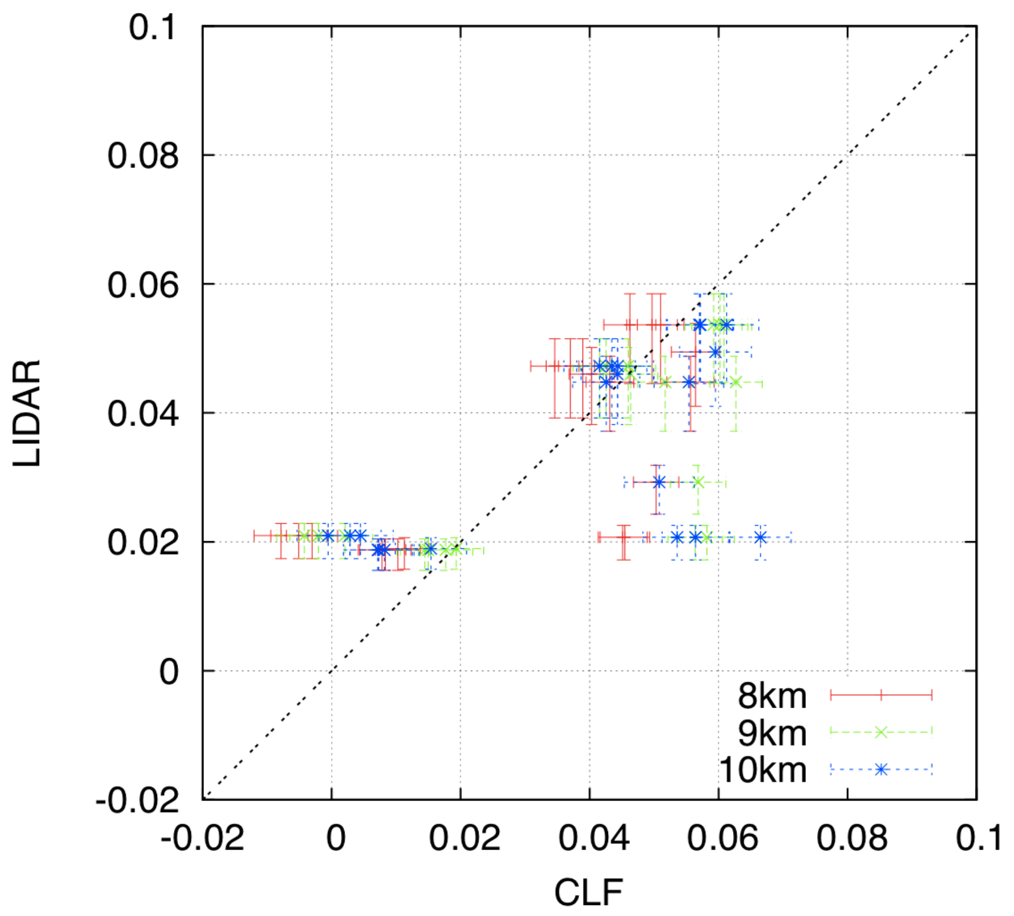
Comparison between BR and LR (2009.08.26～2010.02.14)





- •VAOD of LR is larger than 6% more BR.
- •The adjustment of de-polarization was shifted slightly in this observation term.
- •The likely influence of de-polarization adjustment.
- •For future, I will confirm in another observation term.

Comparison between LIDAR and CLF

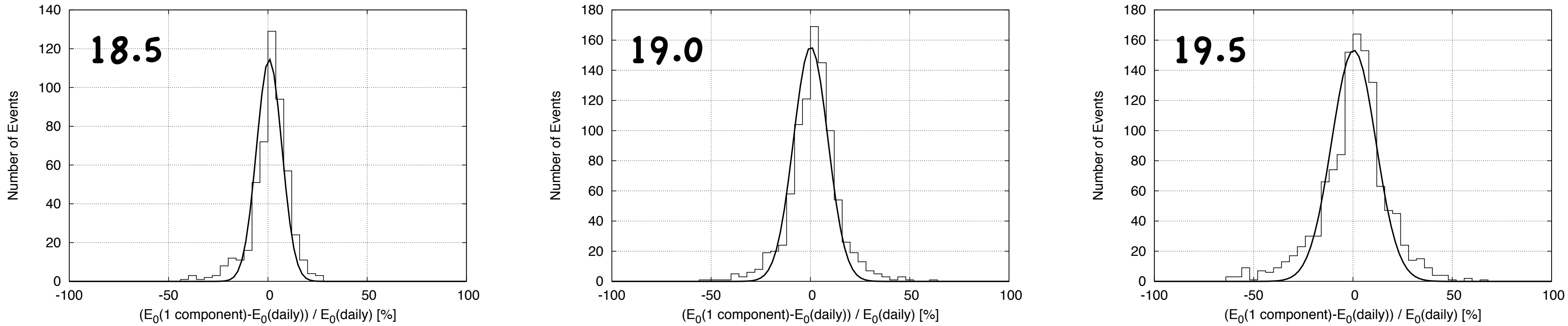


Conditions

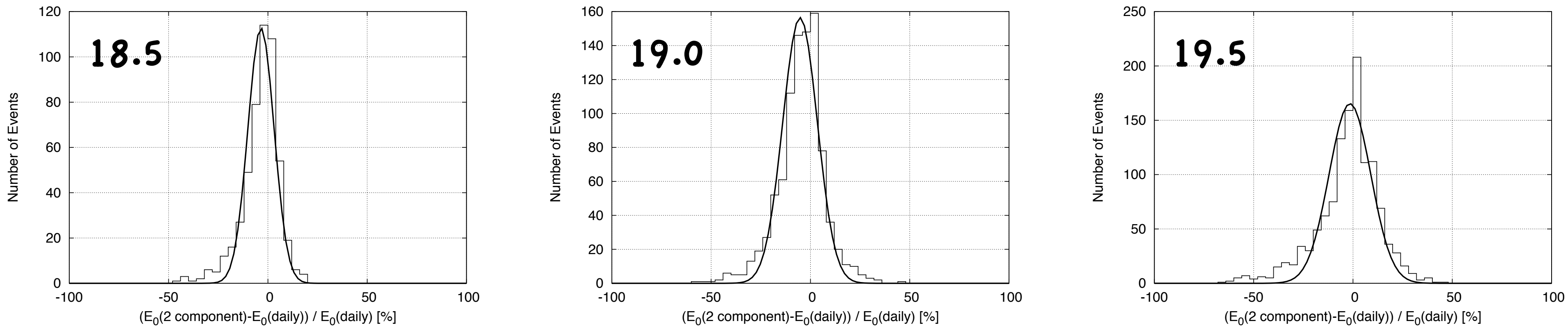
- ■2009.Sep～2009.Dec
- ■No cloud
- ■$|Time^{lidar} - Time^{CLF}| < 1hr$

Effects on energy by atmospheric fluctuation

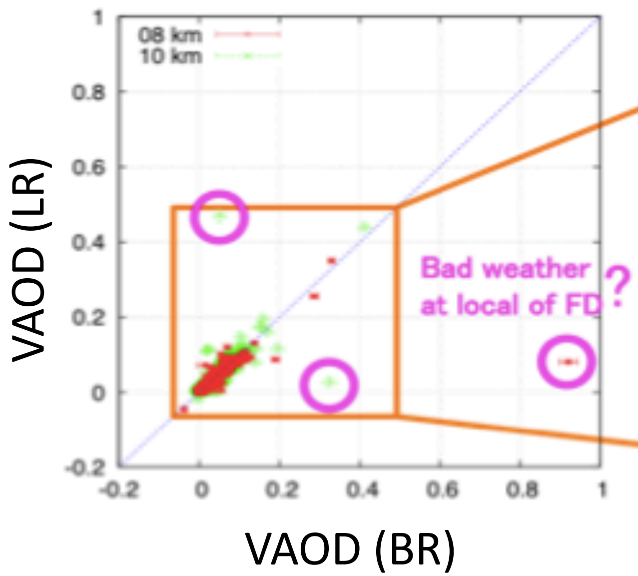
single component

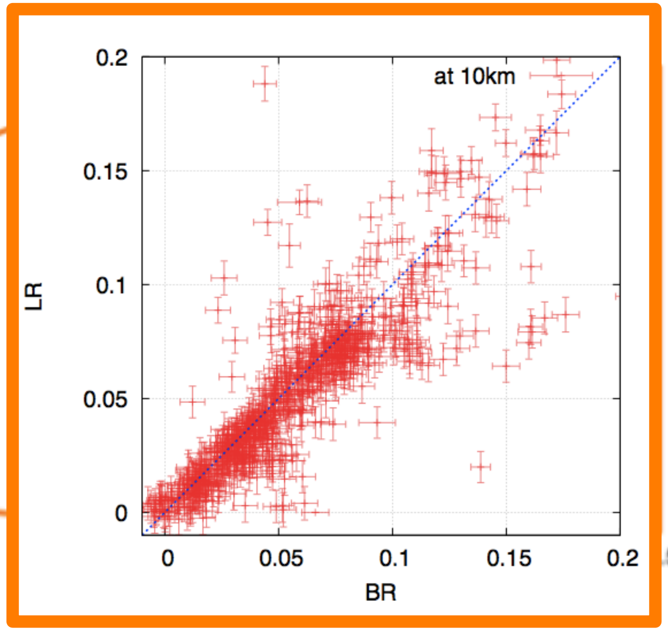


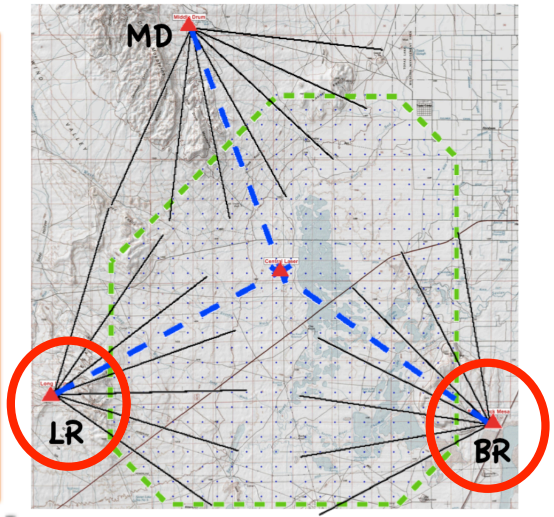
double component



Comparison of BRM and LR







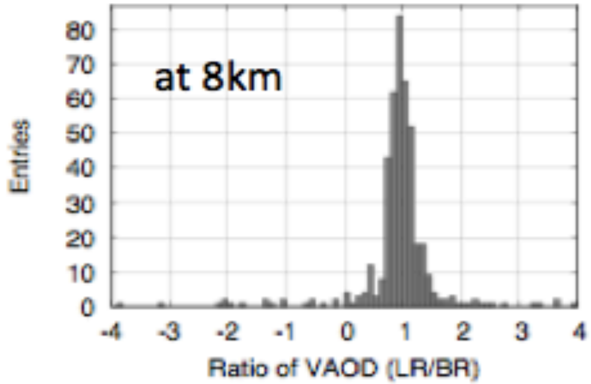
The Ratio of BRM and LR every-observation

@ 8km

BRM:LR = 1.000 : 0.963

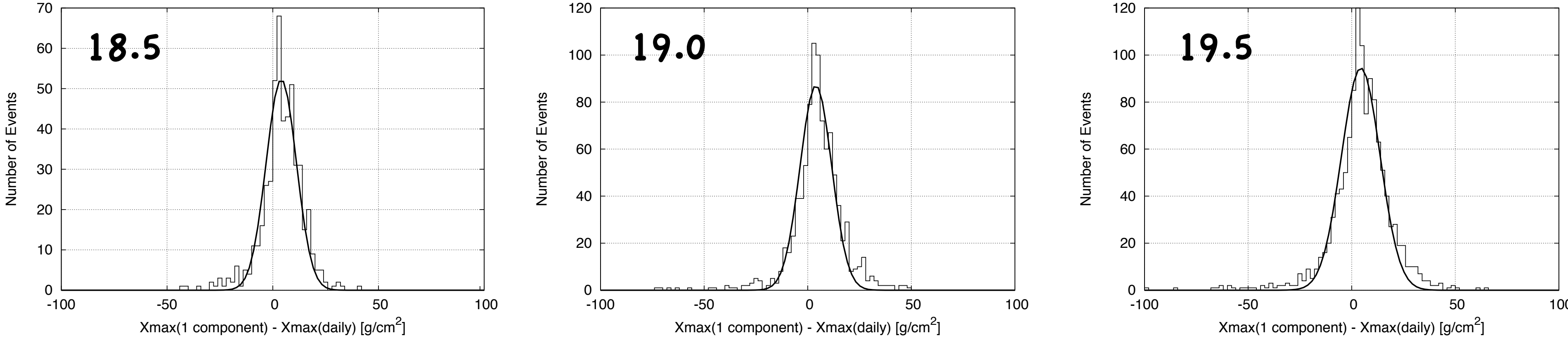
@10km

BRM:LR = 1.000 : 1.004

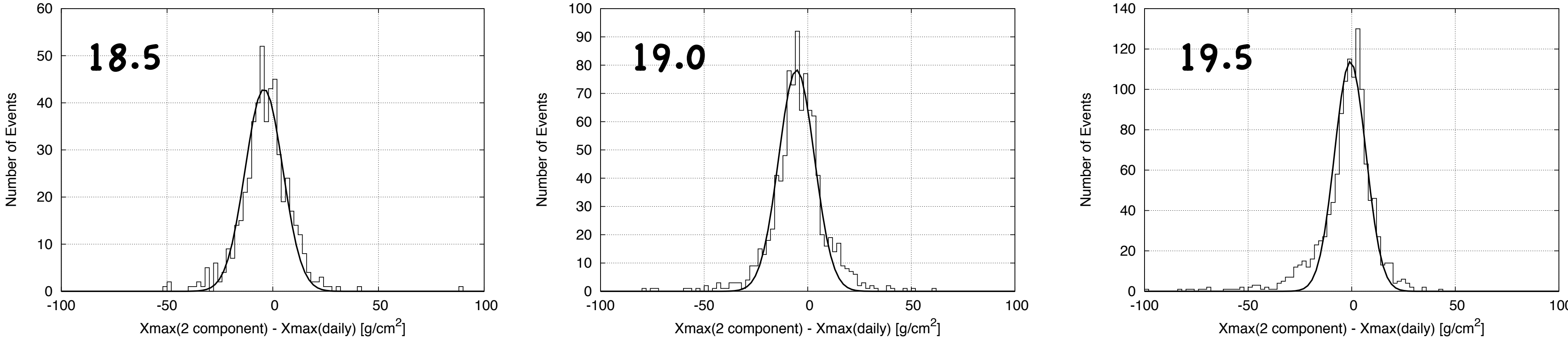


Effects on Xmax by atmospheric fluctuation

single component

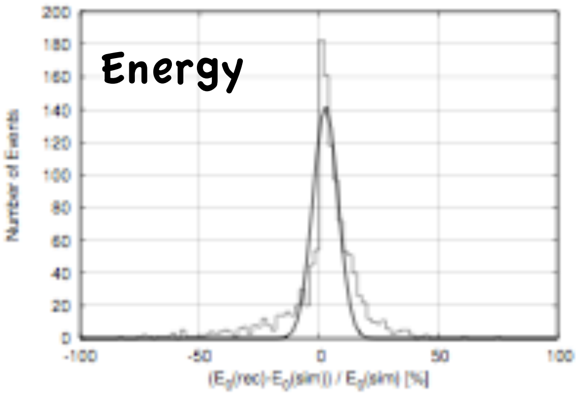


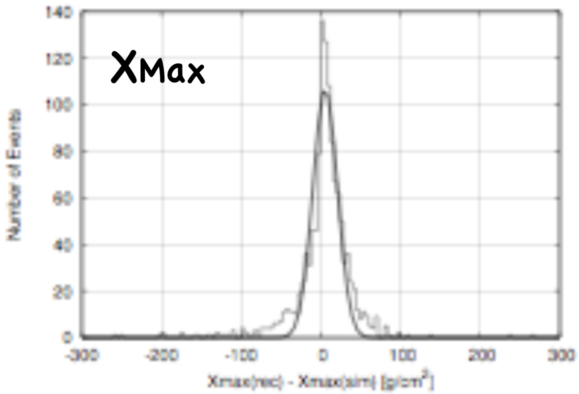
double component



Fluctuation of reconstruction by each atmospheric

logE=19.5 eV





$$\frac{\Delta E}{E_{sim}} = \frac{E_{rec} - E_{sim}}{E_{sim}}$$

$$\Delta X\max = X\max_{rec} - X\max_{sim}$$

result of reconstruction by each atmospheric

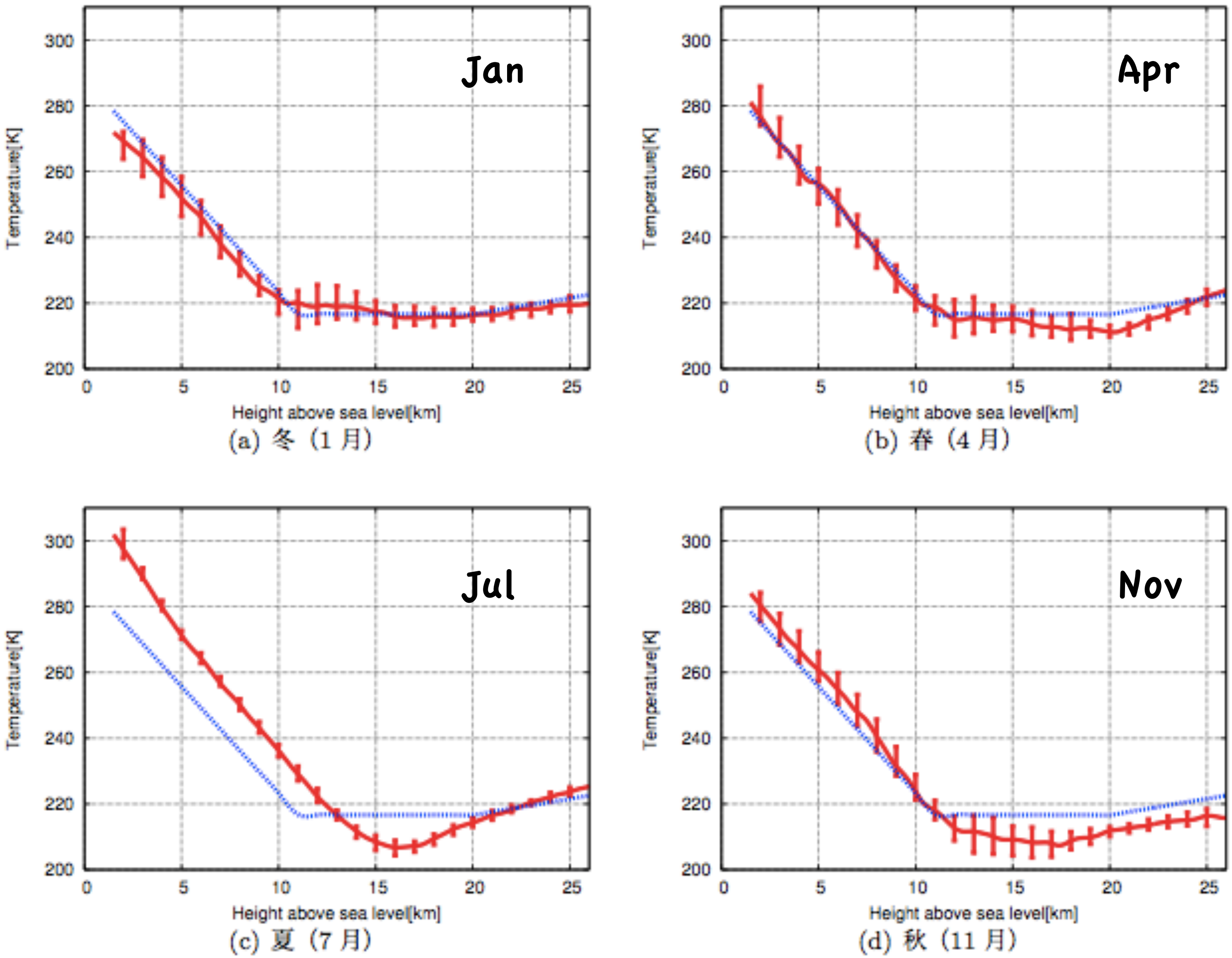
E_0[eV]	#sim.	#trig.	Atmos.	#rec.	#sel.	ΔE_0[%]	ΔX_{Max}[g/cm^2]
$10^{18.5}$	2720	593	daily	556	505	1.94 ± 4.86	0.87 ± 14.11
			1 exp.	553	502	4.63 ± 10.05	5.61 ± 17.9
			2 exp.	553	502	0.28 ± 9.60	2.02 ± 19.31
$10^{19.0}$	2720	1112	daily	1060	930	2.78 ± 5.02	3.86 ± 14.40
			1 exp.	1057	919	5.34 ± 11.94	8.36 ± 17.70
			2 exp.	1056	919	0.38 ± 11.01	0.62 ± 18.72
$10^{19.5}$	2720	1543	daily	1459	1221	3.19 ± 5.19	6.39 ± 15.13
			1 exp.	1457	1206	3.30 ± 16.35	11.33 ± 20.11
			2 exp.	1460	1224	1.58 ± 15.21	4.93 ± 18.96

The fluctuation Including the reconstruction bias using atmospheric model at each energy are

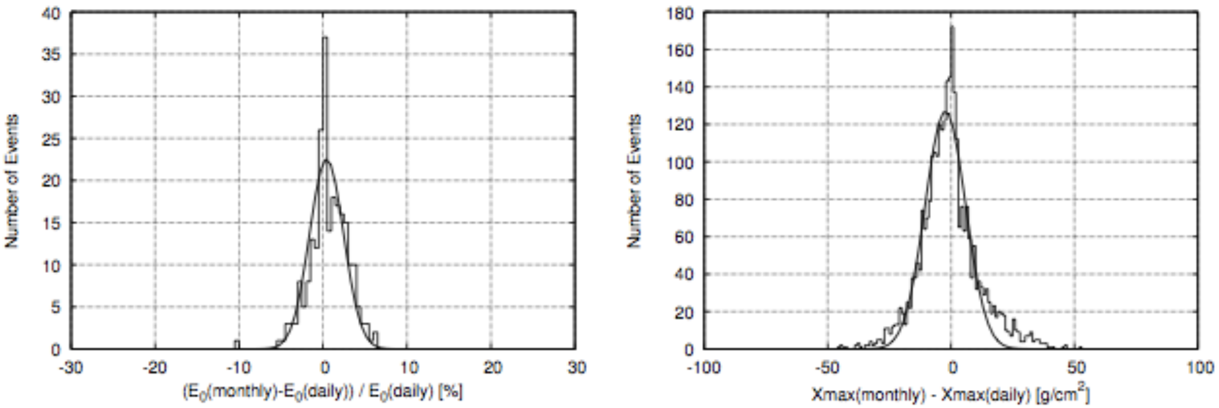
Rec. ΔE : 10%@18.5
12%@19.0
16%@19.5

Rec. ΔXmax : 19g@18.5
18g@19.0
10g@19.5

Rayleigh scattering



Fluctuations by using the Monthly average



(e) $E_0 = 10^{19.5}$eV (f) $E_0 = 10^{19.5}$eV

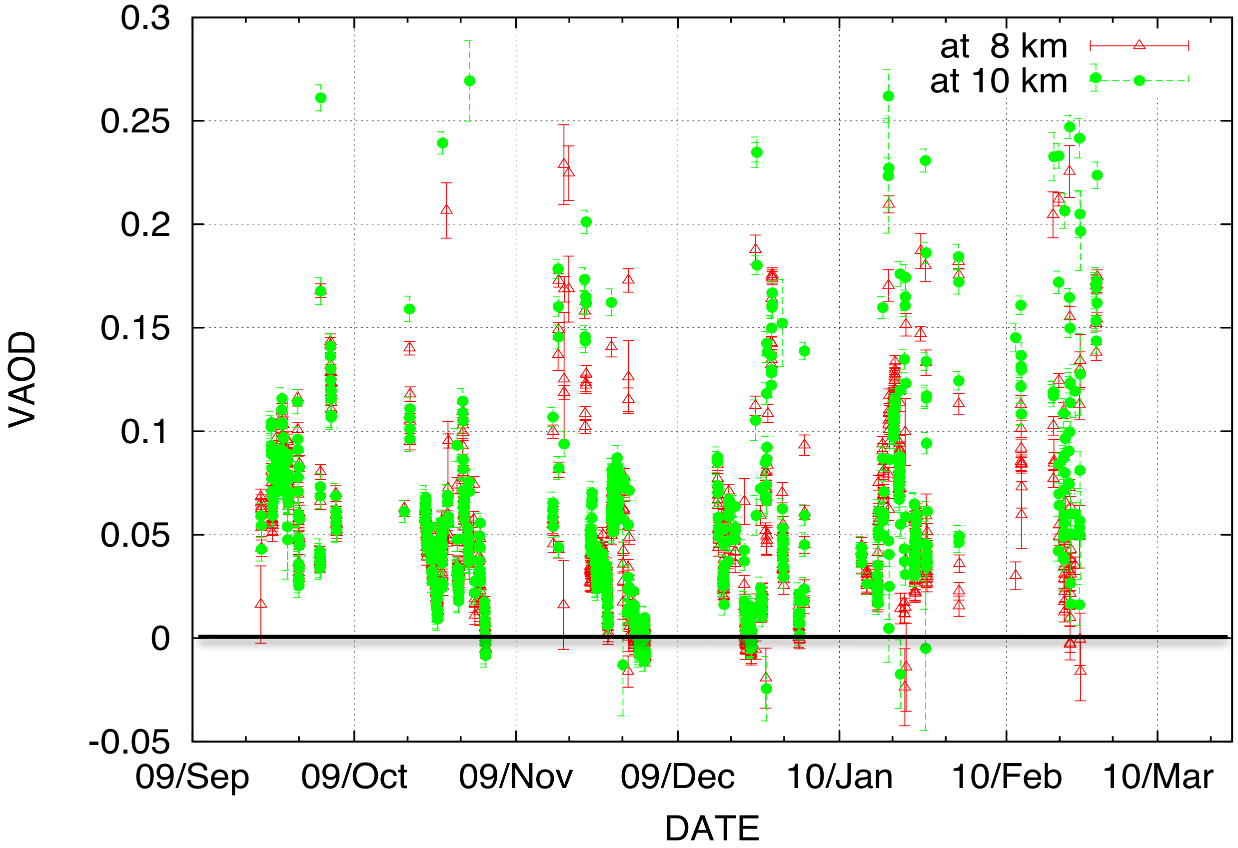
$$\frac{\Delta E}{E_{Daily}} = \frac{E_{Monthly} - E_{Daily}}{E_{Daily}}$$

$$\Delta X\max = X\max_{Monthly} - X\max_{Daily}$$

E_0[eV]	両方の大気状態で解析に成功したイベント数	ΔE_0[%]	ΔX_{max}[g/cm^2]
$10^{18.5}$	1171	-0.16 ± 0.89	-2.50 ± 7.78
$10^{19.0}$	2146	-0.25 ± 1.29	-2.41 ± 7.83
$10^{19.5}$	2883	0.07 ± 1.62	-2.29 ± 8.18

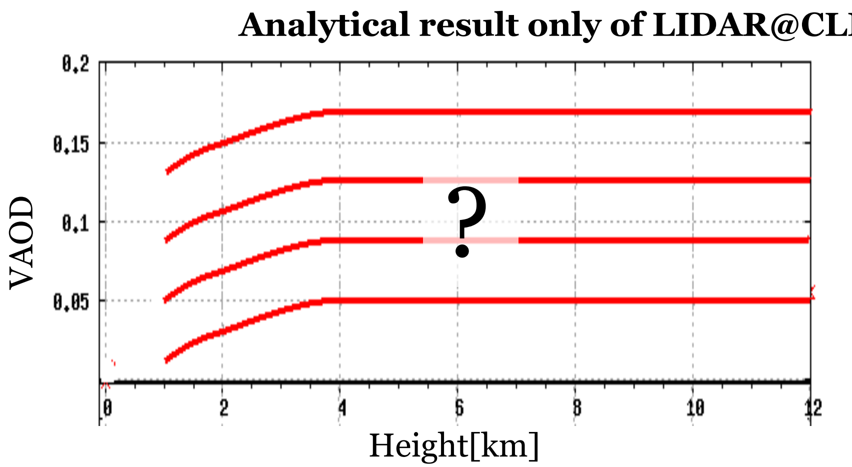
Date variation of VAOD

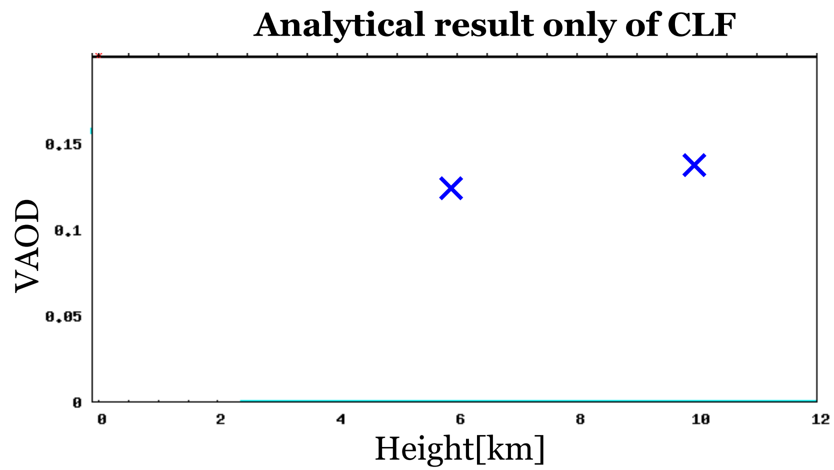
@8km & 10km



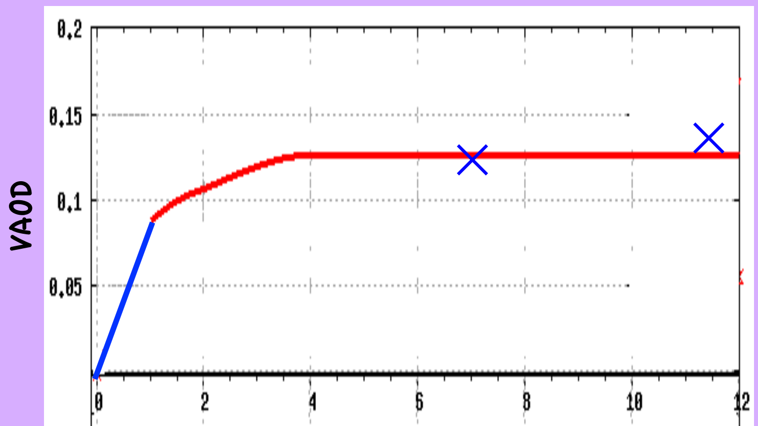
- Winter atmosphere may be clear.
- There is correlation with LIDAR.

Analysis policy of LIDAR@CLF





Normalized by VAOD of CLF.



Analytical result of LIDAR@CLF and CLF

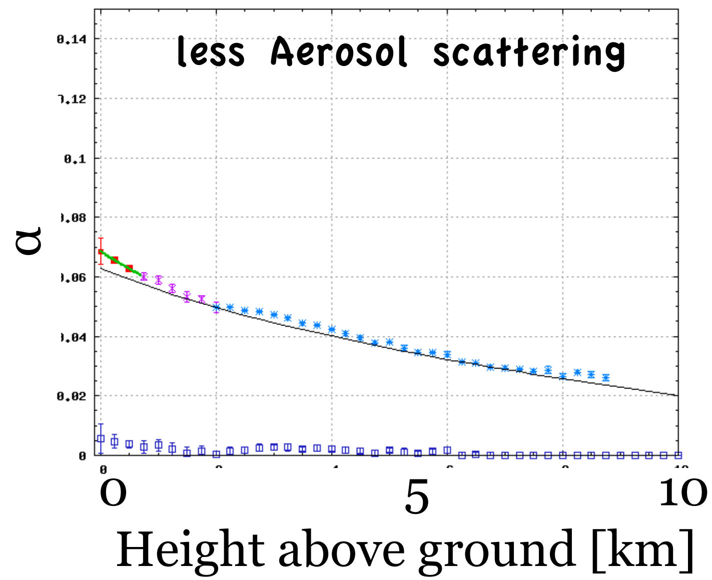
- Shape of VAOD according to height is determined from LIDAR@CLF.
- VAOD at high altitude is determined from the analysis of CLF.

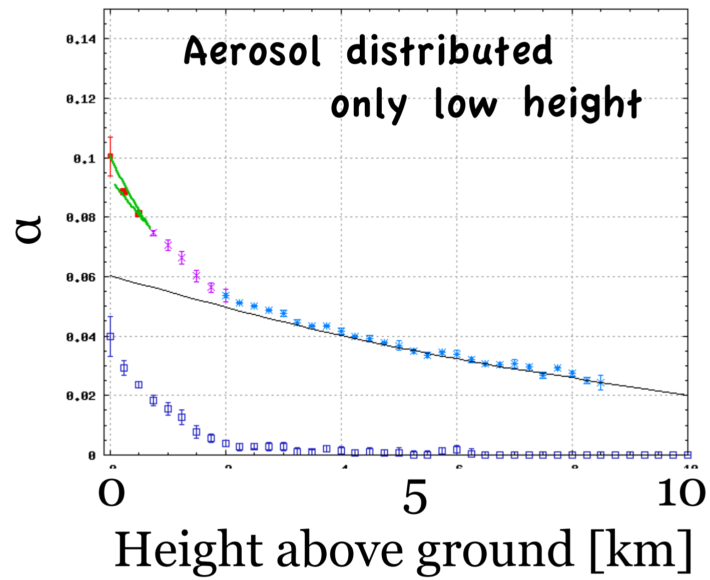
Fluctuation of FD reconstruction using atmospheric transparency by the LIDAR measurement.

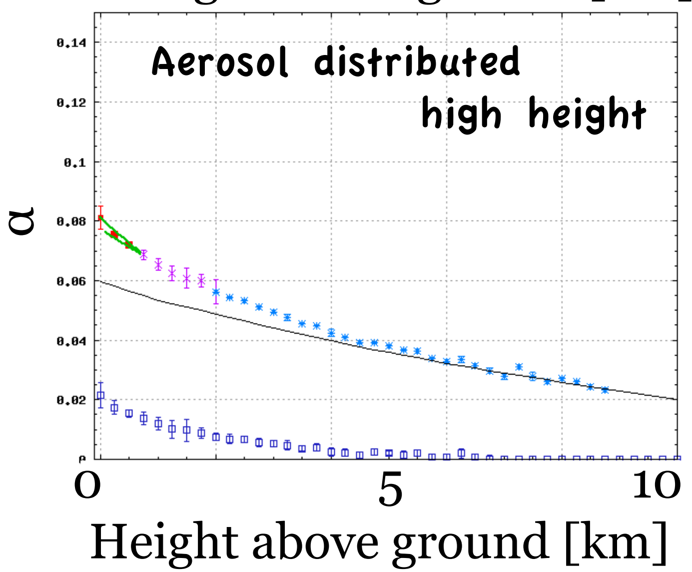
Typicals of Extinction Coefficient

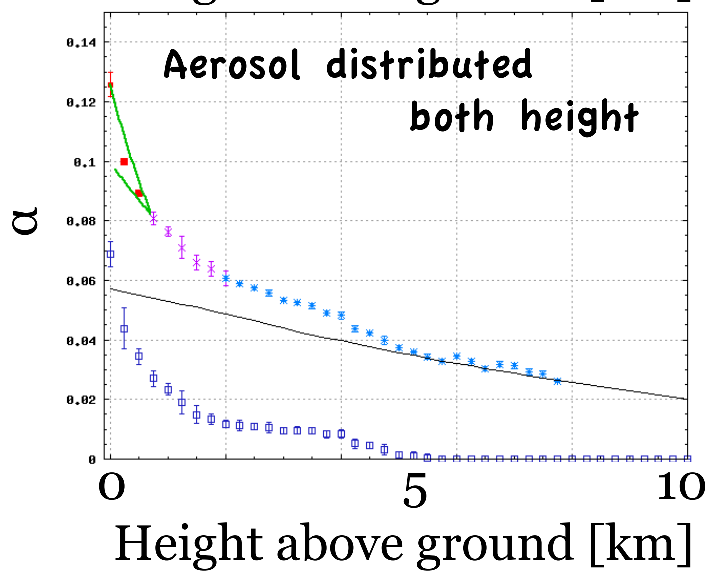
$$Np = Np_0 \exp(-\alpha x)$$

$$\alpha_{AS} = \alpha_{obs} - \alpha_{Rayleigh}$$



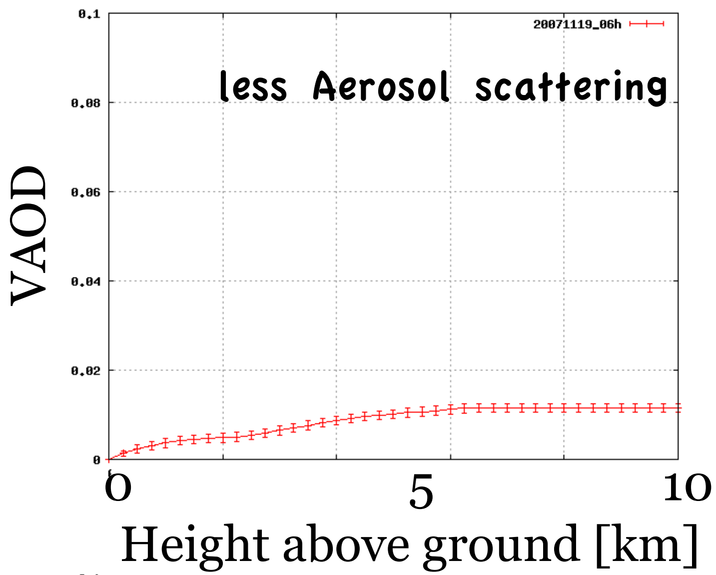


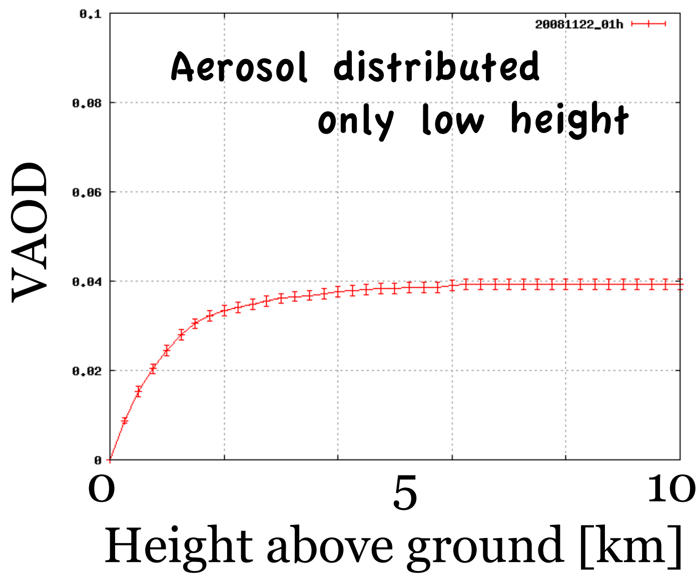


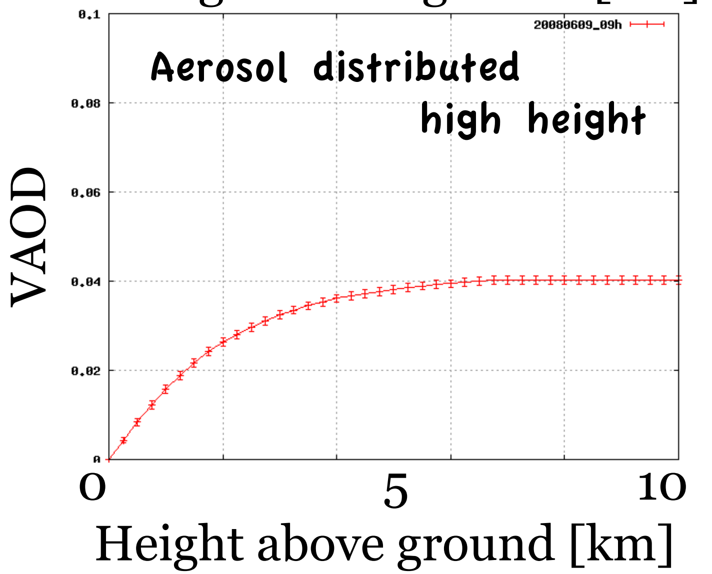


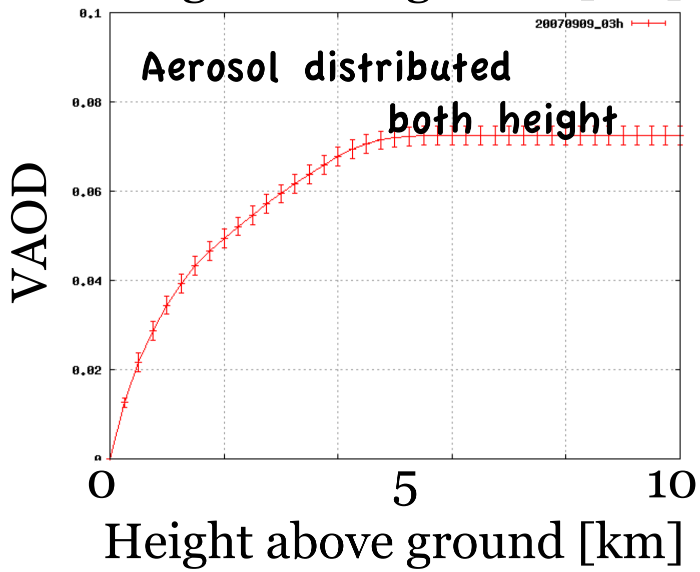
Typicals of VAOD

$$\alpha_{AS} = \alpha_{obs} - \alpha_{Rayleigh} \longrightarrow VAOD(h) = \int_0^h \alpha_{AS}(h)dh$$









Analysis method

FADC count

FD calibration

By Udo-san

Np : Number of photon on the mirror surface

Power of the laser

Np / Power of the laser

Averaging W.F. of 1 obs. & The Average per 500m

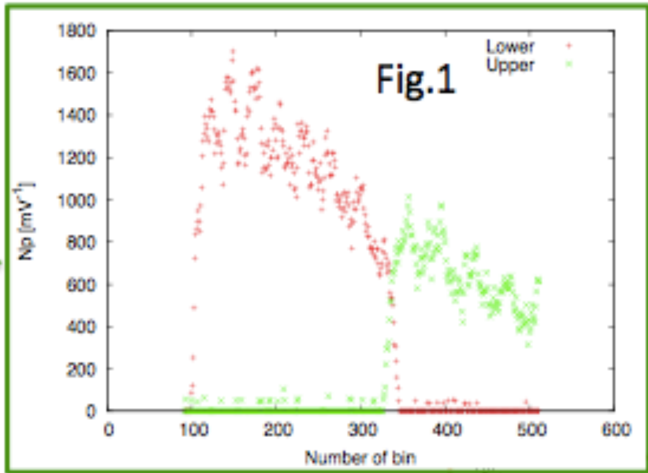
Determination of Cloud

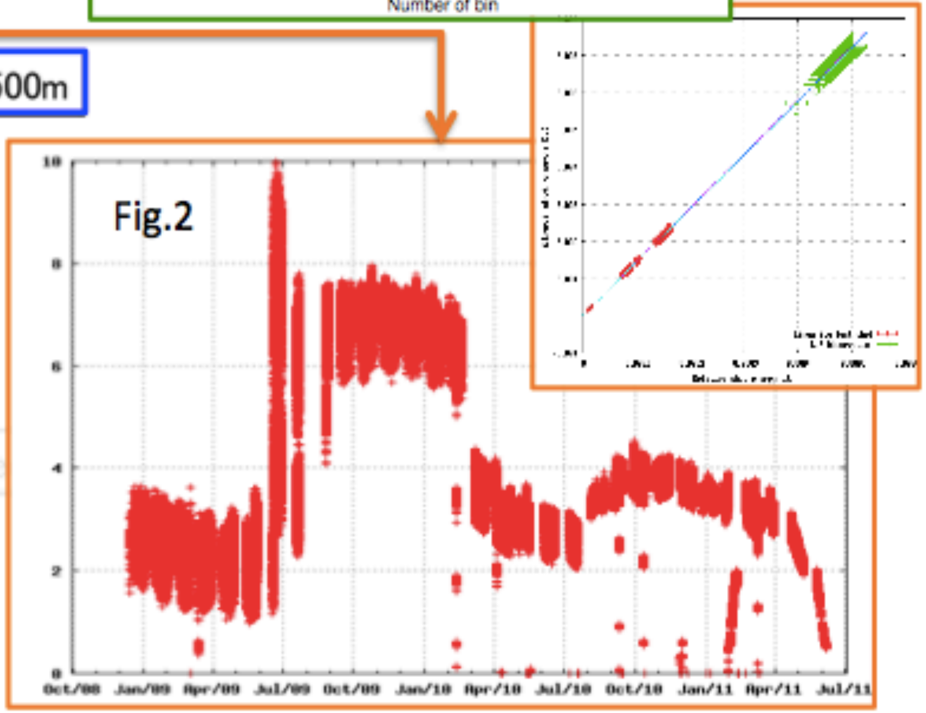
Candidate for the base data (BRM & LR)

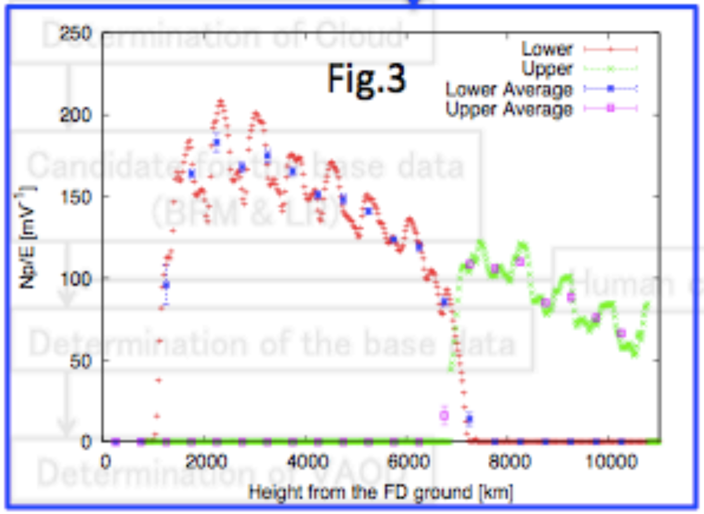
Human check

Determination of the base data

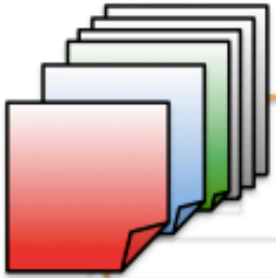
Determination of VAOD







Analysis method



1. To analyze all the data of basis as observations that are passed the data of the quality cut of clouds.

$$\frac{\frac{Np}{E}}{\frac{Np_{ideal}}{E_i}} = \exp\left(-\frac{1+\sin\theta}{\sin\theta}\tau_{AS}(h)\right)$$

2. If higher than higher the atmospheric transparency, the greater the amount of light receiving at high altitude. (Except for the scattering by clouds)
3. If you analysis by using lower atmospheric transparency for based-data, you get a negative VAOD from higher atmospheric transparency.
4. Using the criteria, to select 30 of candidates data in the best atmospheric transparency at LR and BRM in each.
5. Select from the candidates of the same time observations of LR and BRM, and reference data consider a temporal continuity.

Determination of Cloud

Candidate for the base data (BRM & LR)

Human check

Determination of the base data

Determination of VAOD

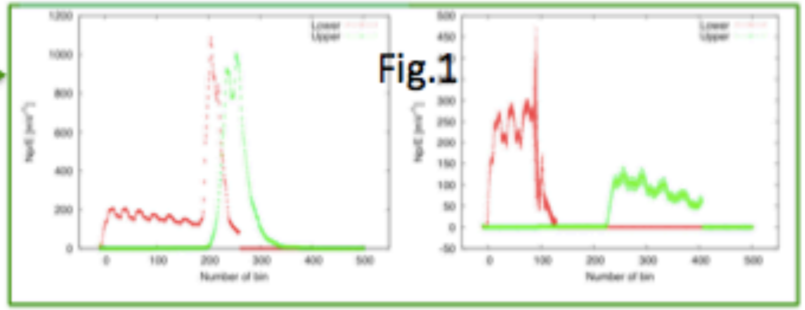
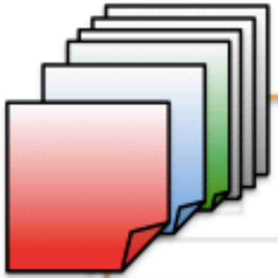


Fig.1

Analysis method



1. To analyze all the data of basis as observations that are passed the data of the quality cut of clouds.

$$\frac{Np / E}{Np_{ideal} / E_i} = \exp\left(-\frac{1+\sin\theta}{\sin\theta}\tau_{AS}(h)\right)$$

2. If higher than higher the atmospheric transparency, the greater the amount of light receiving at high altitude. (Except for the scattering by clouds)
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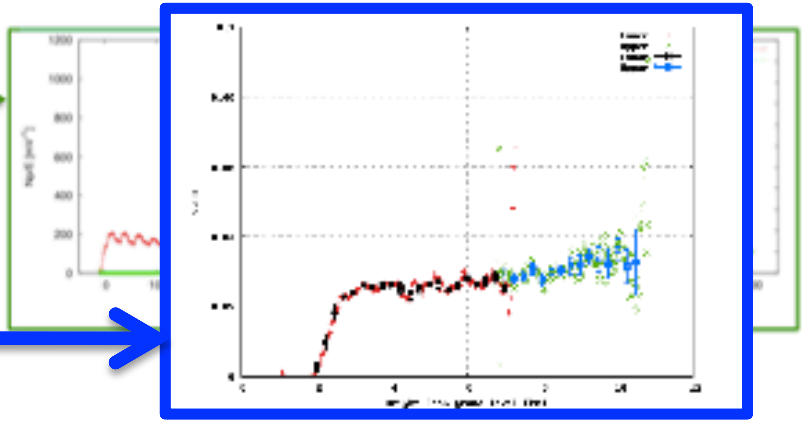
Determination of Cloud

Candidate for the base data (BRM & LR)

Human check

Determination of the base data

Determination of VAOD



Simulation conditions

- Primary energy : logE= 18.5, 19.0 and 19.5 eV
- Direction: Zenith is between 0 ~ 60 ° (the isotropic)
  Azimuth is between 0 ~ 360 ° (the isotropic)
- Core position : within 25 km of the CLF (center of TA FDs).
- Number of event : 20 events at each energy for each of 136 good LIDAR runs.
- Quality Cuts : Reconstructed X_{max} in field of view of FD.

↓

Reconstruction using

Daily atmospheric data or two atmospheric **models**