National Institute of Information and Communications Technology

NOAA Working Group on Space-Based Lidar Winds
(*May 13, 2014, Best Western Plus Boulder Inn, Boulder CO*)

Feasibility Study for Super Low Altitude Satellite borne Doppler Lidar (S-LIDAR)

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Outline

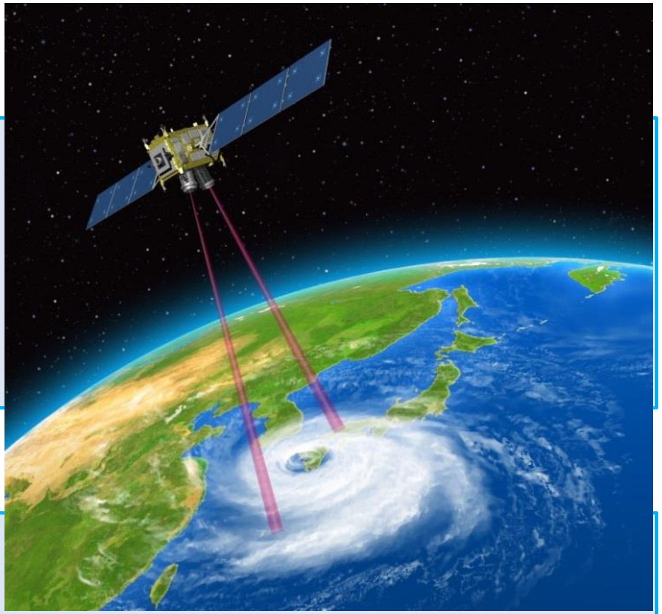
- Background
- Study on feasibility
  - Bas
    - Orbit
    - Electrical Power
    - Heat budget
  - Lidar
    - 2μm-Laser
  - Simulation
    - Lidar simulator (ISOSIM-L)
    - Observing System Simulation Experiment (OSSE)
- Summary

Background

Typhoon and wind observation by Doppler lidar

Background and objectives

- ◆Three-dimensional distribution of wind is not enough: ground-based measurement (mainly land), ocean surface wind or atmospheric motion vector (cloud or vapor, specific layer, indirect information).
- ◆Three-dimensional distribution of wind is very important to develop NWP, climate model, many other meteorological studies and so on.
- ◆World's first coherent Doppler lidar: wind vector, 3D observation of aerosol/clouds.



Concept

- ◆Coherent Doppler LIDAR
  - ➢ Eye-safety
  - ➢ Multi directions (at least 2 directions)
- ◆Technical subject
  - ➢ Single frequency eye-safe high-power laser
  - ➢ Heterodyne receiver

Expected results

- ◆Global distribution of aerosol/clouds along satellite track
  - ➢ Improvement NWP
  - ➢ Improvement of prediction and prediction accuracy for occurrence, path, intensity, size of typhoon
  - ➢ Improvement of prediction and prediction accuracy for atmospheric transport model such as radio active materials, air pollutant, yellow sand, and so on
  - ➢ Validation and accuracy improvement of AMV measured by geostationary satellite
- ◆Single frequency space qualified laser for continuous efforts on spaceborne lidar mission

Plan for Doppler Wind lidar measurement from space

衛星搭載ドップラーライダーによる風観測実施計画書

ドップラーライダによる宇宙からの風観測を考える検討会
2013/03/18

- Our working group proposed a new basic idea of spaceborne Doppler lidar in March 2013:
- Chapter I: Technology and progress of Doppler lidar
- Chapter II: Current status and issue of data assimilation on numerical weather prediction
- Chapter III: Science plan of spaceborne Doppler lidar

After feasibility study in FY2013

- Chapter IV: Spaceborne Doppler wind lidar measurement
  - Outline of Mission program
  - Science requirement
    - Bas
    - inclination angle, coverage, period
    - data acquisition system
  - Road map (schedule)

Chapter IV=> next revision.

Report (60 pages) is written in Japanese.

Study on feasibility of Bas

Super Low Altitude Test Satellite

Super Low Altitude Test Satellite (SLATS) is a satellite under development in JAXA.

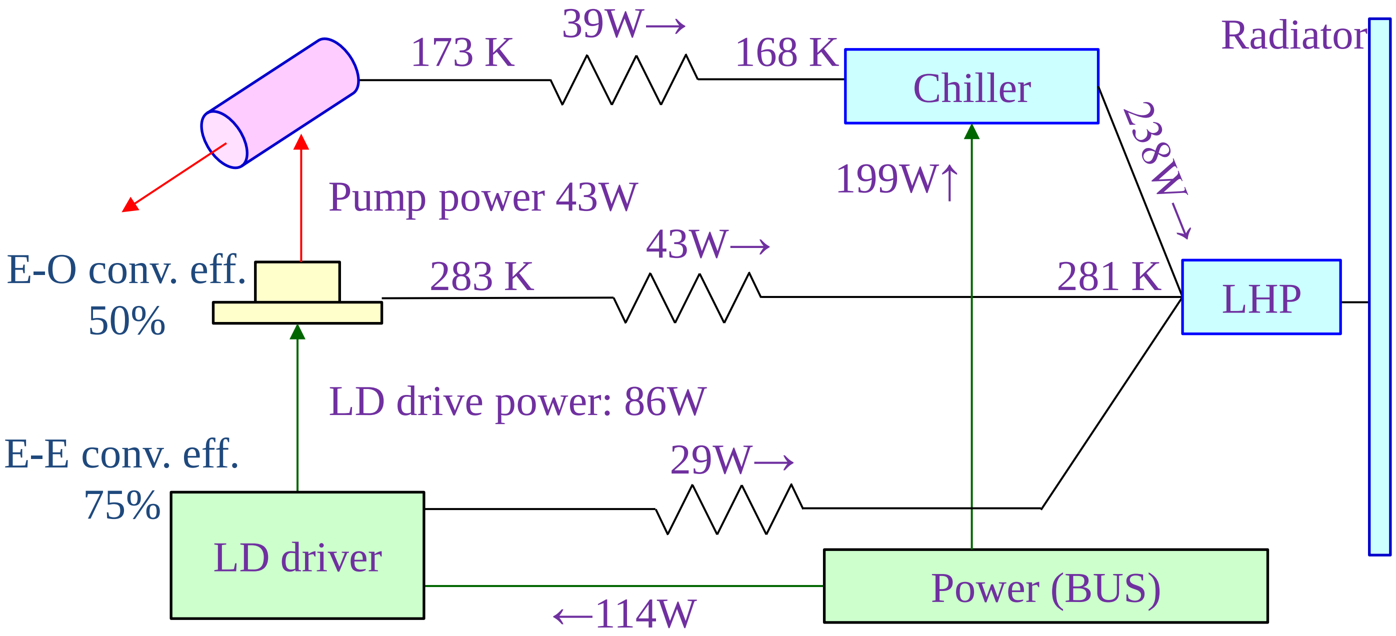
- Key concept
  - Ion engines is used for compensation of air drag in lower altitude
  - Target altitude ranging from 200 km to 230 km
- Advantages of this technology compared to typical earth observation satellites whose altitude ranging from 600 km up to 700km
  - Resolution: 1/3
  - Necessary Power for Lidar(light detection and ranging): 1/9
  - Transmitted Power of SAR: 1/27
- Disadvantage
  - Swath: 1/3
- Additional Features
  - Exploiting Japanese superior technologies such as ion engine
  - Target weight: 300 up to 1000 kg
  - Prospective and competitive in some type of missions
  - Candidate of Small satellite platform for specific users

(https://eeepitnl.tksc.jaxa.jp/mews/en/23rd/data/10-03.pdf)

Requirement, constraint and assumption

	ISS-borne Coherent Doppler LIDAR (JEM-CDL)	S-LIDAR
Orbit	350-400 km 51.6 degree inclination	220km Inclination
Instrument volume	1.82 × 0.95 × 0.76 m^3	1.5 × 1 × 1 m^3
Mass	500 kg (instrument, NET)	600 kg (Bus + instrument)
Power	540 W (instrument, NET; 1 laser)	1600 W
Pulse energy	500 mJ	125 mJ
Pulse Repetition Rate	10 Hz	30 Hz
Telescope	0.4 m (primary mirror) x 1 or 2	0.4 m (primary mirror) x 2
Horizontal resolution	100Km	100Km
Vertical resolution	Altitude 0-2km: 0.5 km Altitude 2-5 km: 1km	Altitude 0.5-3 km: 0.5 km Altitude 3-8 km: 1 km Altitude 8-20 km: 2 km
Nadir angle	30 degree	~35 degree
Looking angle	90 degree	45 and 135 degrees along direction of travel

Thermal requirement



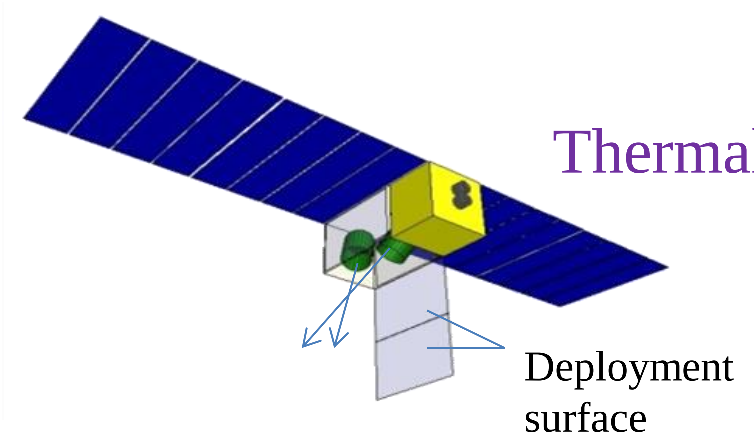
Laser rod	**O-O conversion efficiency**	**8.8%**
Pumping LD	**E-O conversion efficiency**	**50%**
	Average power	**85.2W/LOS**
LD driver	**E-E conversion efficiency**	**75%**
	Average power	**114W/LOS**
Chiller average power		**199W/LOS**
Electric devises average power		**60W**
Total instrument average power		**685W**
Amount power of laser waste heat		**309W/LOS**
Total amount power of laser waste heat		**678W**

Thermal design (constraint and assumption)

We designed "radiation surface area" under following conditions:

- Constraint
  - Waste power : 730 W
  - Radiator surface area : 1.26 (=1.4 × 0.9) m^2/ 1 panel
  - Radiator field view efficiency : 0.61*
  - Radiation efficiency : 0.70
- Assumption
  - Instrument is adiabatically separate from bus.

*We assume that a rdiator exists in the field of view.



Thermal design result

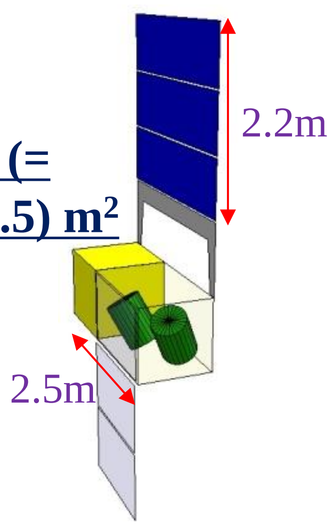
=> **4 radiator panels**

Power consideration (constraint and assumption)

We designed "radiation surface area" under following conditions:

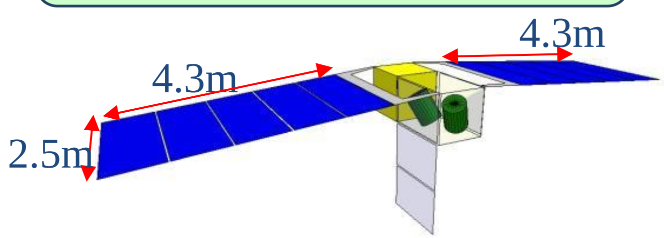
- <u>Constraint</u>
  - Total power (consumption) :1600 W*
  - Solar radiation :1300 W/m^2
  - Solar Array Panel (SAP) Conv. Eff. :0.25 (3 coupled cell)
  - SAP installation :fixed wing**
  - Orbit :Sun-synchronous polar orbit (LST18)
    Low inclination orbit

<u>5.5 (= 2.2×2.5) m^2</u>

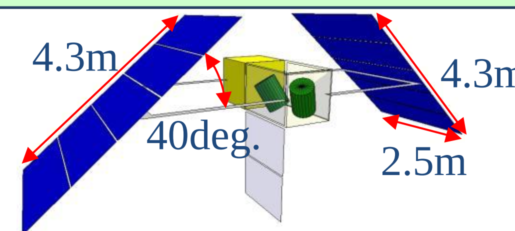


Sun-synchronous polar orbit
Sun incident angle = 66.6-90deg

CASE 1



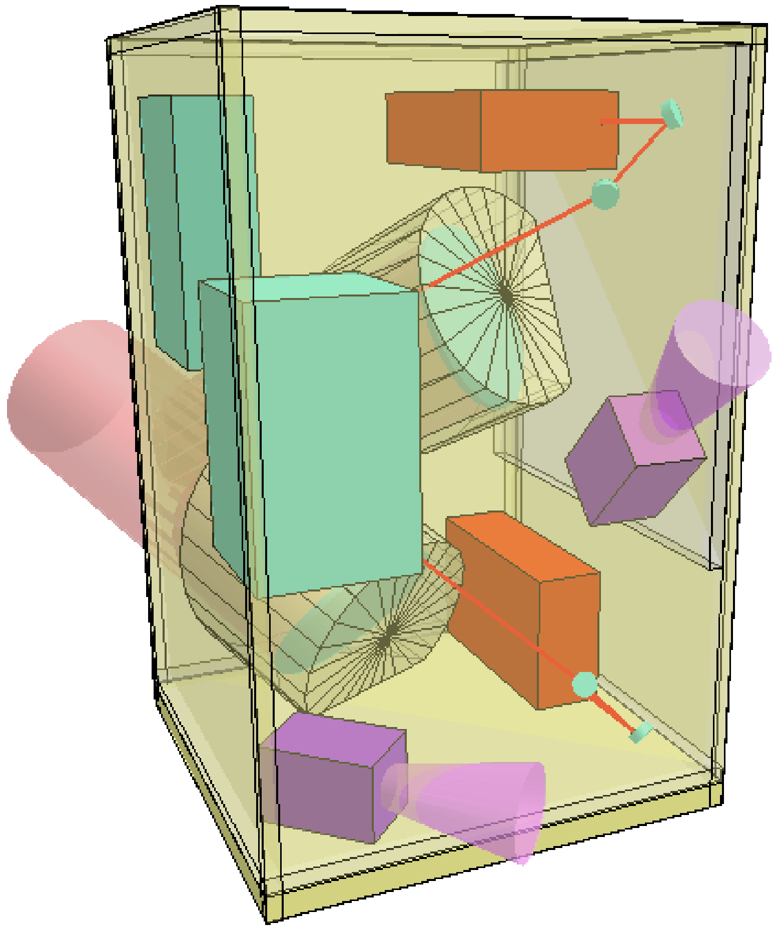
CASE 2



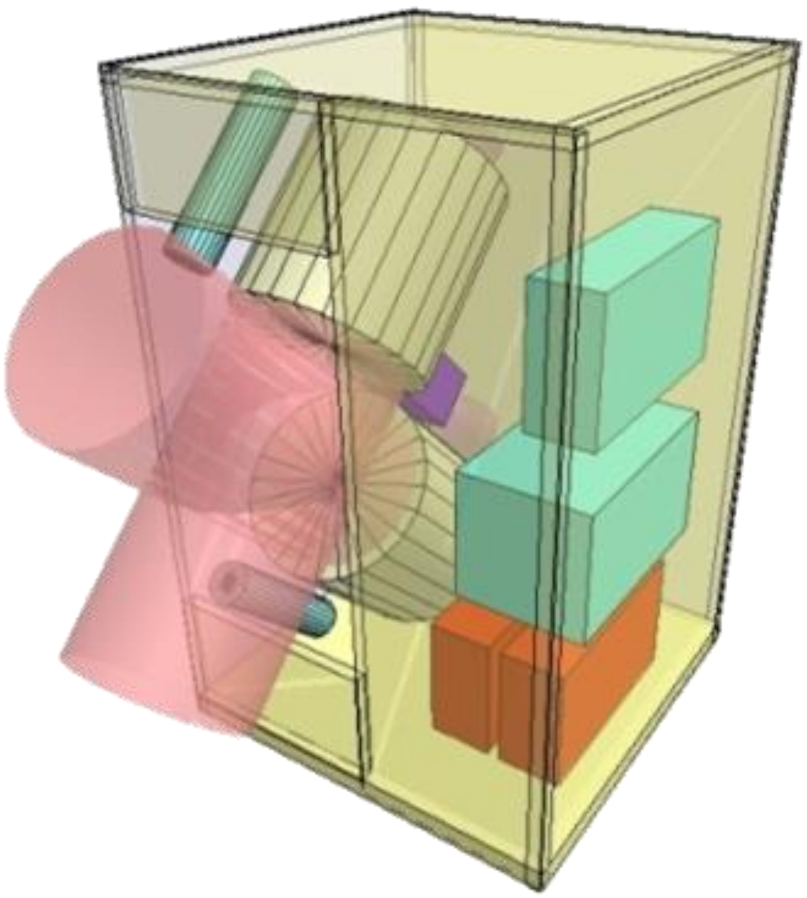
<u>10.8 (=4.3×2.5) m^2</u>

	Sunlight incident angle	SAP	Cant angle
Case 1	0-20 deg	**<u>10.8 m^2</u>**	0-20deg.
Case 2	20-45deg	**<u>10.8 m^2</u>**	~40deg.

Mechanical configuration



Example 1



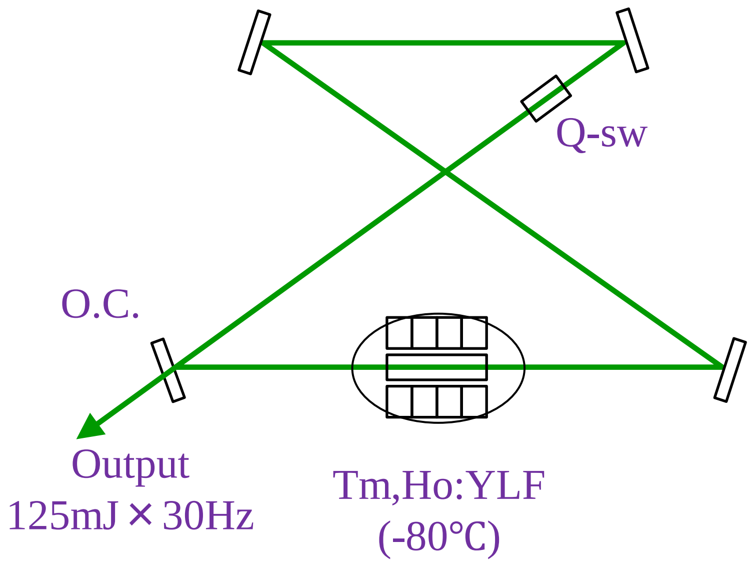
Example 2

External volume of telescope: $\pi\ (\Phi 50/2)^2 \times 50\ [cm^3]$

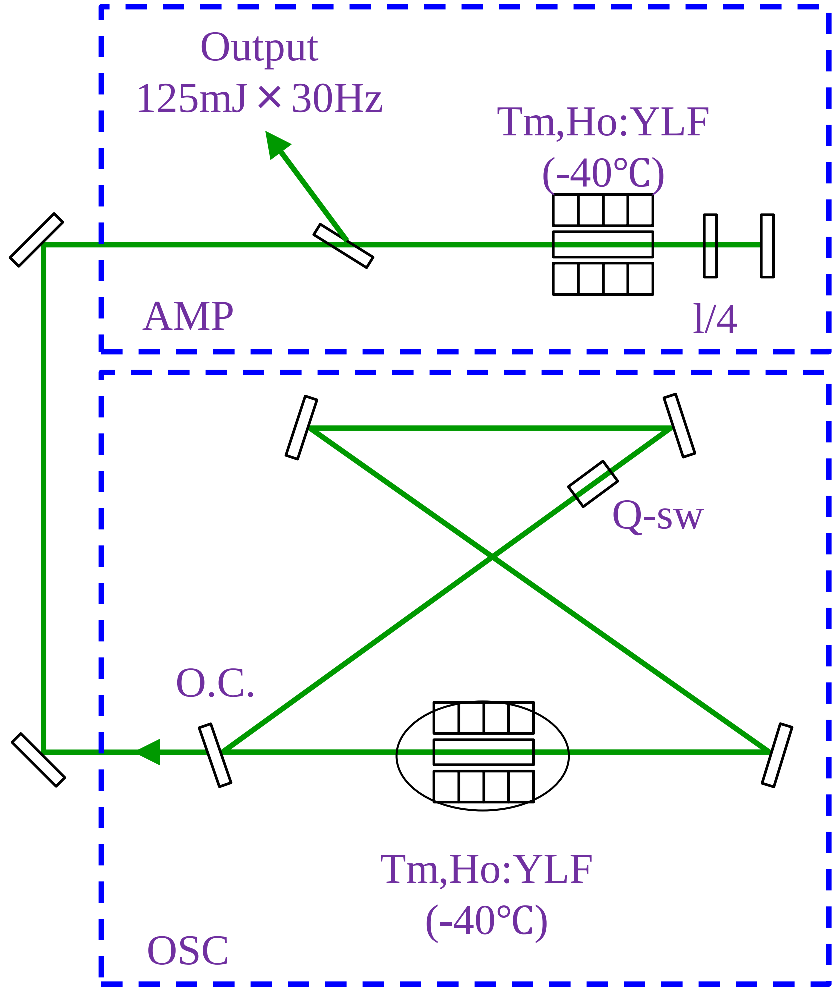
Lidar
2μm Laser

2μm laser block diagram

1 Oscillator



1 Oscillator+ 1 Power amplifier



O.C.: Output Coupler

Laser design (constraint and assumption)

We designed 2-μm laser under following conditions:

- Constraint

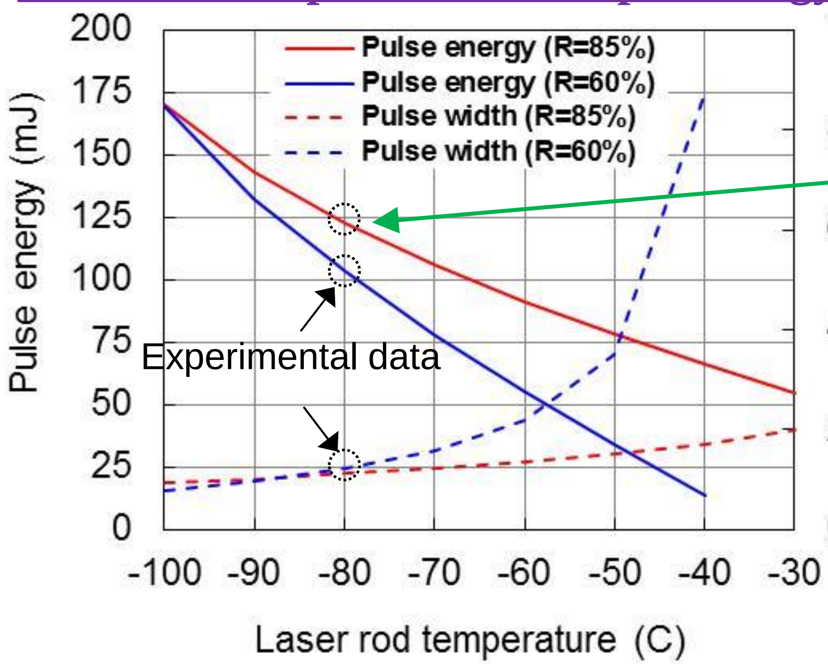
  Fitting with respect to unknown parameters were performed as to be consistent with experimental results:

  - Pulse energy :100 mJ/pulse
  - Pulse width : ~120 ns
  - Laser rod temperature : -80C.

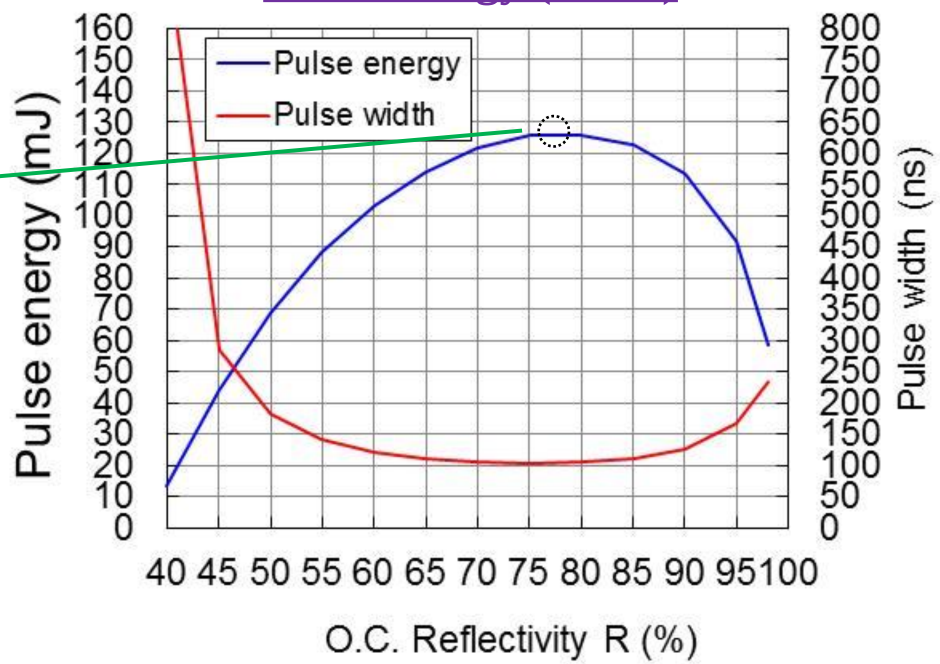
- Assumption
  - Laser rod material :Tm, Ho:YLF
  - Doping concentration :Tm: 4 atm%, Ho:=0.4 atm%
  - Laser rod volume :Φ4mm x 44 mm
  - Laser rod temeperature :-100C (OSC), -40 C(MOPA)
  - Pumping energy :1.4 J
  - Pumping duration :1 msec
  - Pumping frequency :30Hz
  - Cavity length :3.8 m (ring-type)

Output energy (1 oscillator case)

Laser rod temperature vs output energy



Pulse energy (-80 C)

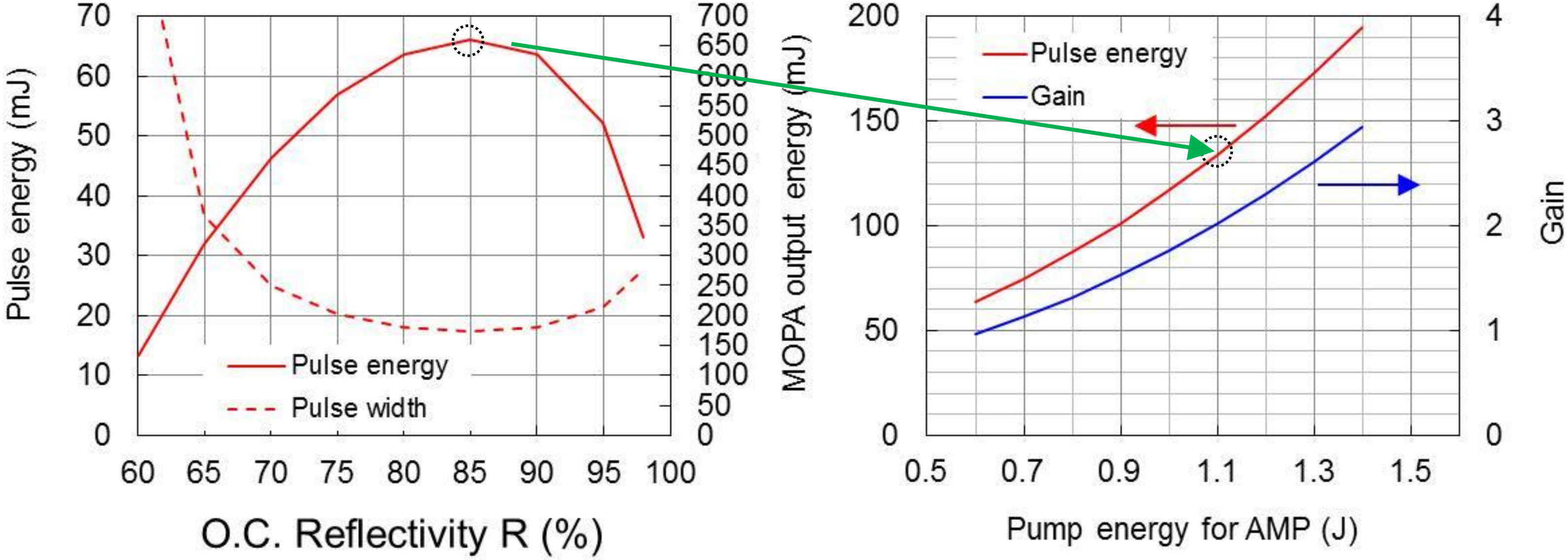


Laser rod temperature was assumed to be -80 C. In order to achieve a pulse energy of 125 mJ, we optimized reflectivity of O.C. The results shows that optimized values are in the range between 70% and 85%. We can also get the high pulse energy by cooling down laser rod temperature to -100 C.

Electric Power = 84 W + 199W (chiller) = 283 W

Output energy (MOPA case)

Laser rod temperature : -40 C
Pump energy for AMP : 1.4J
OC reflectivity : 85%

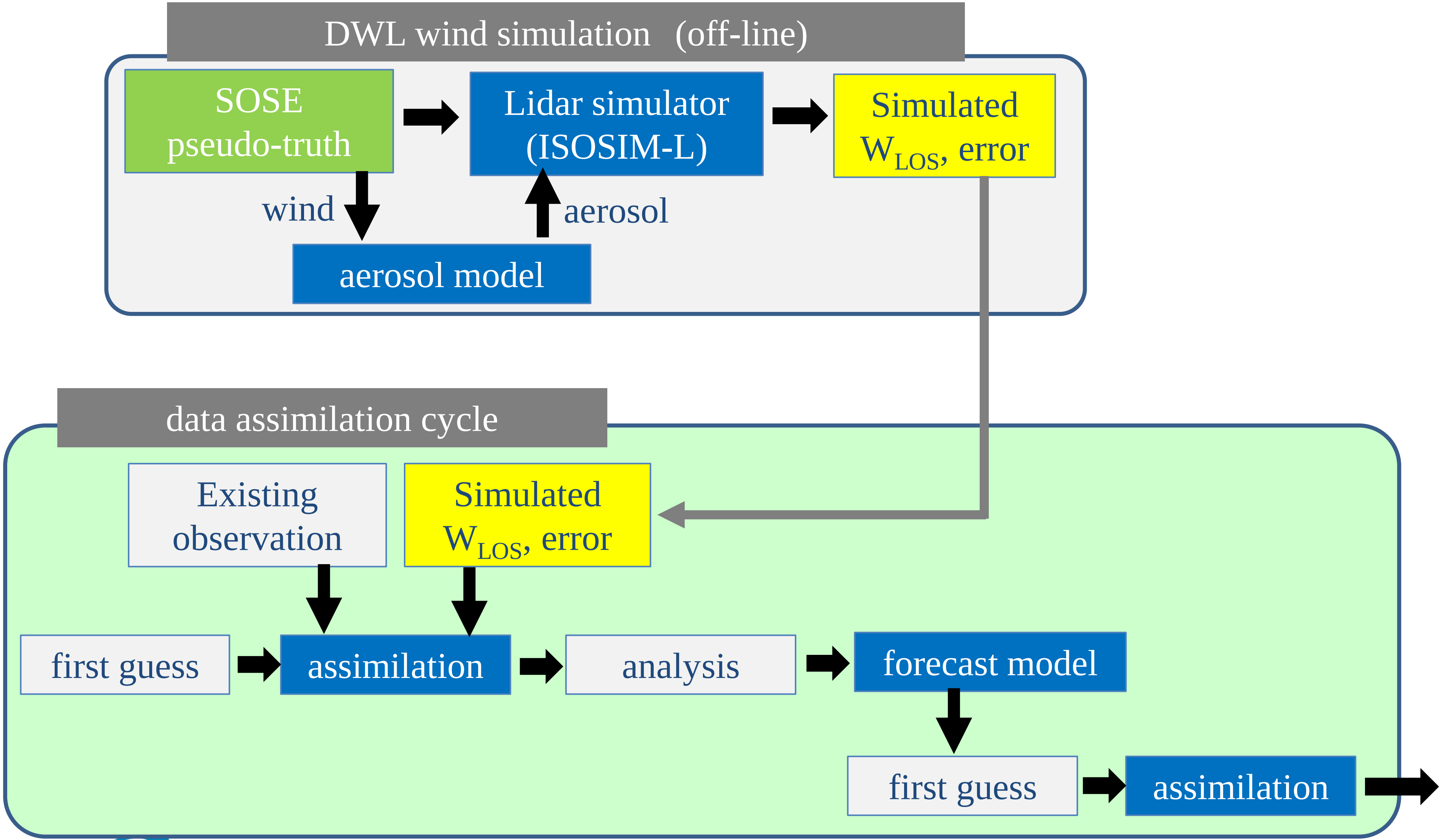


- Simulated results indicated that MOPA laser can emit a target pulse energy of 125mJ at a rod temperature of -40 C. Temperature dependency for simulated results were weaker than for experimental results.
- Wall plugin (OSC + AMP) was estimated to be 2.2% (Target is 4%)
- Electric Power
- OSC (＜84W)＋AMP (＜84W)＋Chiller (Target <110W)

Simulation

1. Lidar simulator (ISOSIM-L)
2. Observing System Simulation Experiment (OSSE)

SOSE-OSSE procedures



SOSE: Sensitivity Observing System Experiment

Parameters

- Simulated atmospheric data (SOSE)
  - August 1-31, 2010, 00Z, 06Z, 12Z, 18Z, 24Z
    - August 1=> July 31.21Z, 22Z, 23Z, 8/1 00Z, 01Z, 02Z, 03Z
  - 60 layers
  - 1.125º × 1.125º grid
  - P, U, V, Cloud coverage, Cloud Water Content, Upward Mass flux [kg/m2/s]
- Aerosol model
  - 48 layer
  - 1.125º × 1.125º grid
  - Composition: sulfate, sea salt, dust, carbon, organic aerosol
    - Backscattering coefficients of each aerosol are calculated using Mie theory.
- Cloud model
  - 48 layer
  - 1.125º × 1.125º grid
  - Type: cumulous cloud, stratus cloud
  - Cloud coverage, Cloud Water Content
- Orbit
  - Polar
  - TRMM
- Output
  - 1 shot data：time, altitude, longitude, latitude, LOS wind speed, wind error, Power, SNR, etc
  - 14 sec average data：time, altitude, longitude, latitude wind speed, wind error, SNR

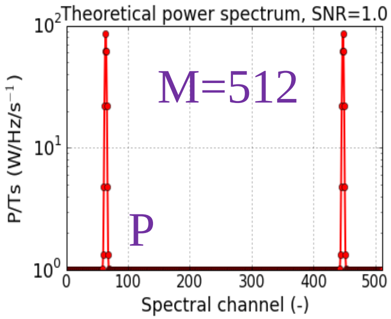
※Altitude: -0.5, 0.1, 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 7, 8, 10, 12, 14, 16, 18, 20 (km)

Signal simulation & LOS wind retrieval

Theoretical power spectrum

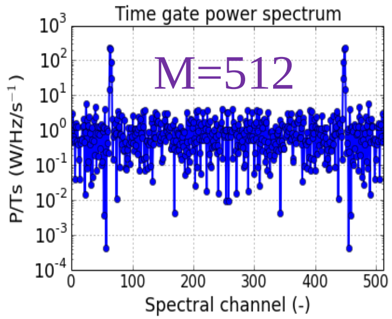
P

SNR = 1,
B = 200 MHz (Ts = 2.5 ns)
Pulse FWHM = 200 ns (~1.56 MHz),
Doppler freq. = 50 MHz.



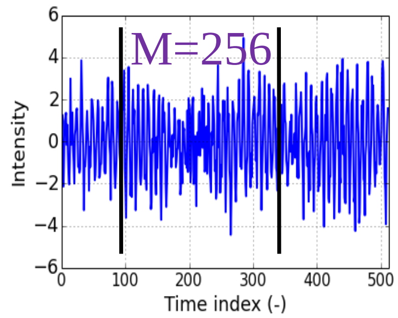
Time gate random coefficient spectrum (high resolution)

B = 200 MHz
df = 0.78 MHz



Simulated time domain signal

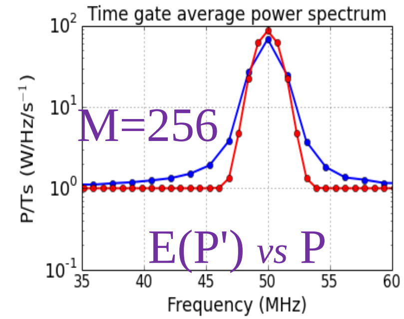
Ts = 2.5 ns
MTs = 640 ns



Simulated Power spectrum

P'

B = 200 MHz
df = 1.56 MHz



E(eps) = 0
E(|eps|²) = M/2Ts P

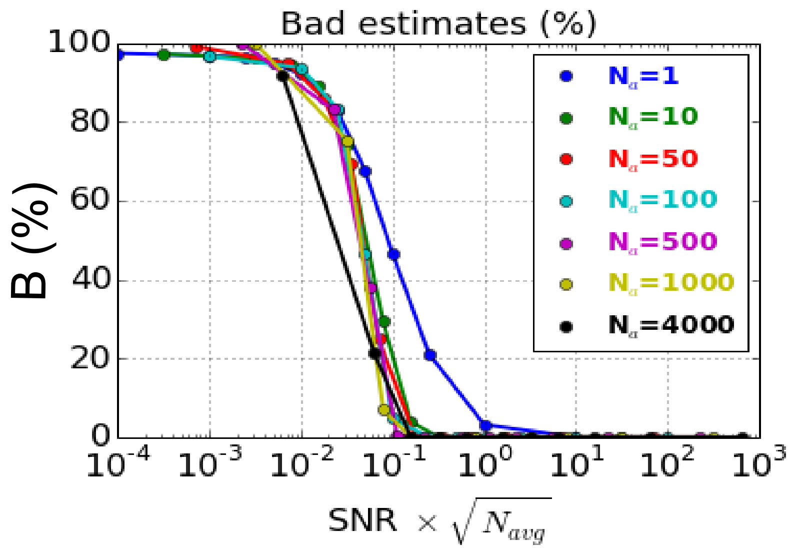
IFFT

eps' = FFT(s)
P' = 2Ts/M |eps'|²

Zrnic, D.: Estimation of Spectral Moments for Weather Echoes, Geoscience Electronics, IEEE Transactions, 17, 113–128, doi:10.1109/TGE.1979.294638, 1979.

Bad estimates statistics: definition of the suited SNR range

B = 200 MHz (Ts = 2.5 ns)
Spectrum resolution = 1.56 MHz (M=256)
Pulse FWHM = 200 ns (~0.96 MHz)
Random line frequency = 50 +/- 5 MHz

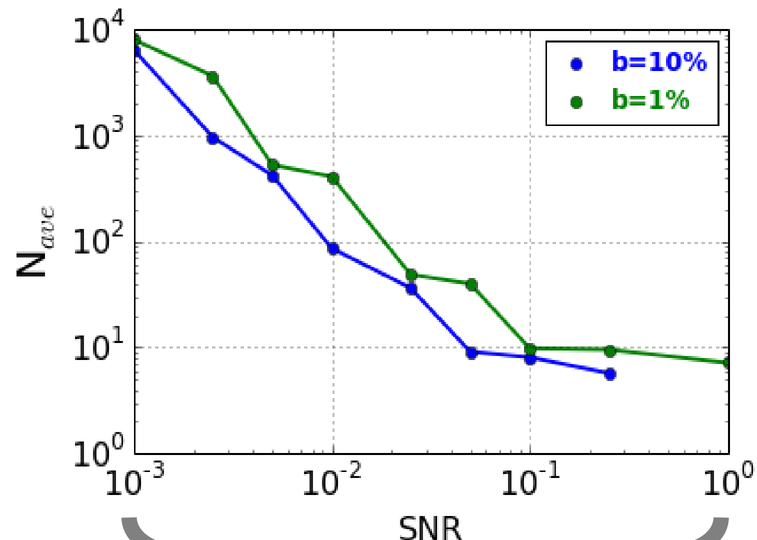


Na is the number of averaged spectra

PRF = 30 Hz, range vertical resolution = 50 m (T=640 ns)

- **100 km horizontal resolution**: N ~ 430 pulses = (100 km) / (7 km/s) * (30 Hz)
- **1 km vertical resolution:** N ~ 20 ranges = (1 km)/(50 m)

Max. number of averaged spectra is 8000

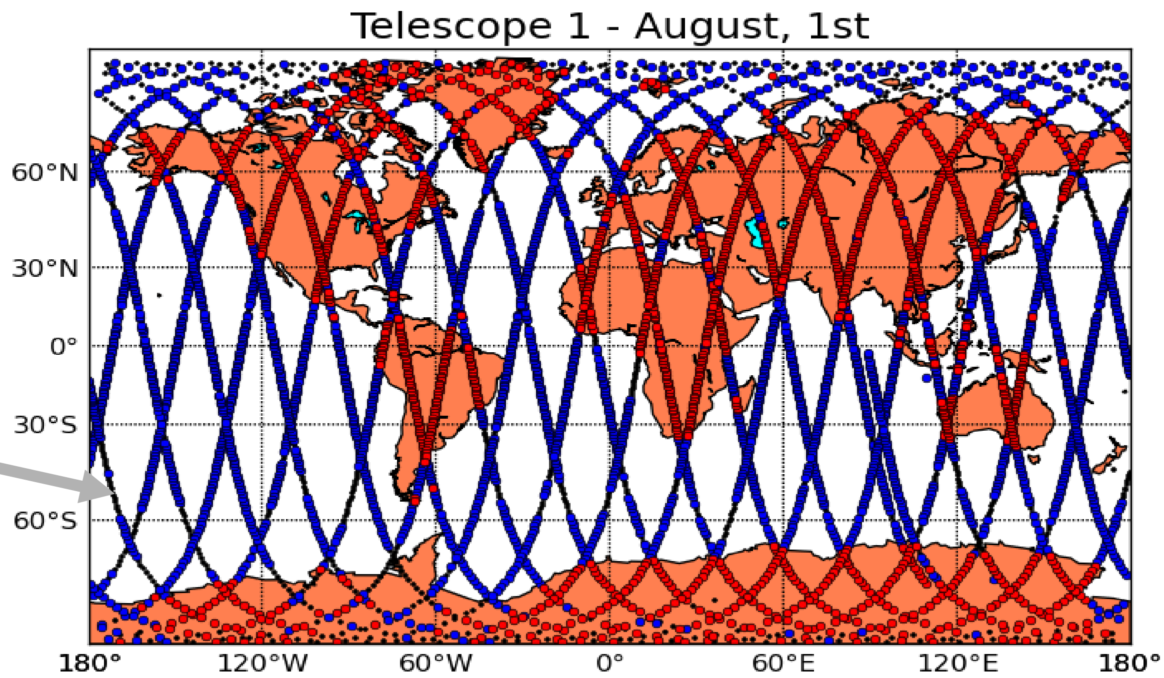


Suited single-range SNR

Example: Surface return for 1-day simulation

Red : SNR>10
Blue : SNR<10
Black : SNR<1

Black dots:
Cloud signal
attenuation

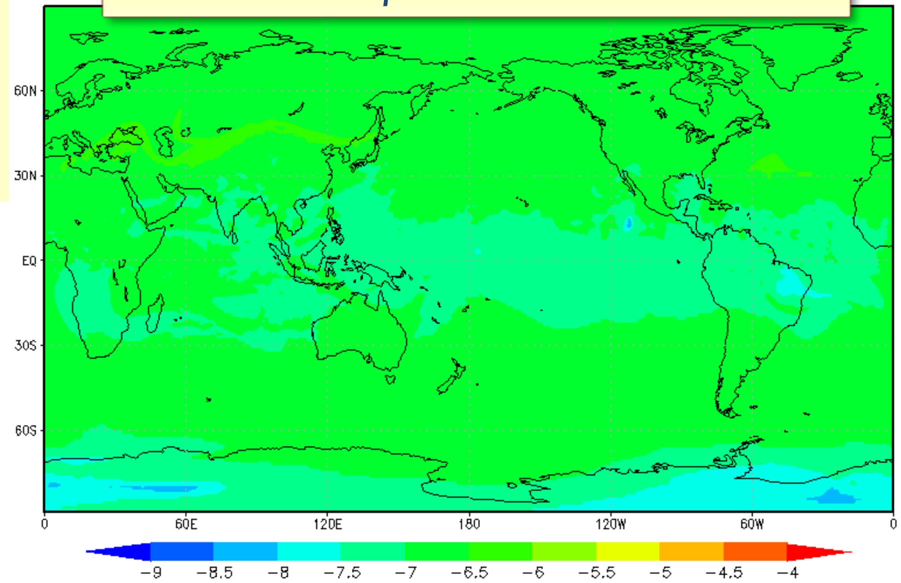


Laser power = 125 mJ, PRF=30 Hz, wavelength: 2050 nm, 100 km horizontal average

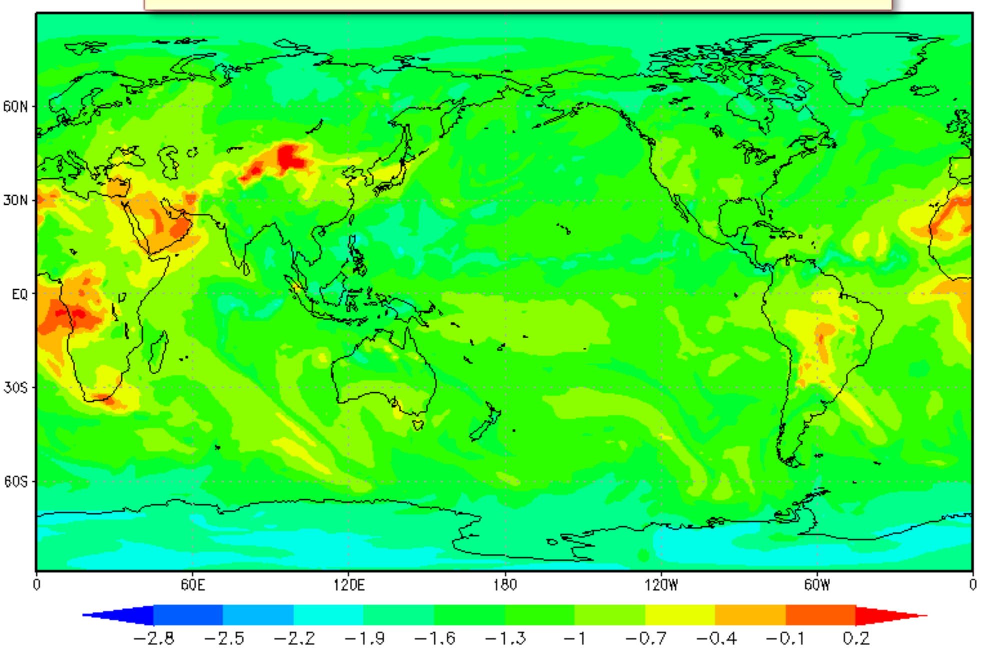
Backscattering coefficient from aerosols

- 00UT, 1 Aug. 2010
- Aerosols: sulfate, dust, sea salt, black carbon
- Optical parameters based on Mie theory

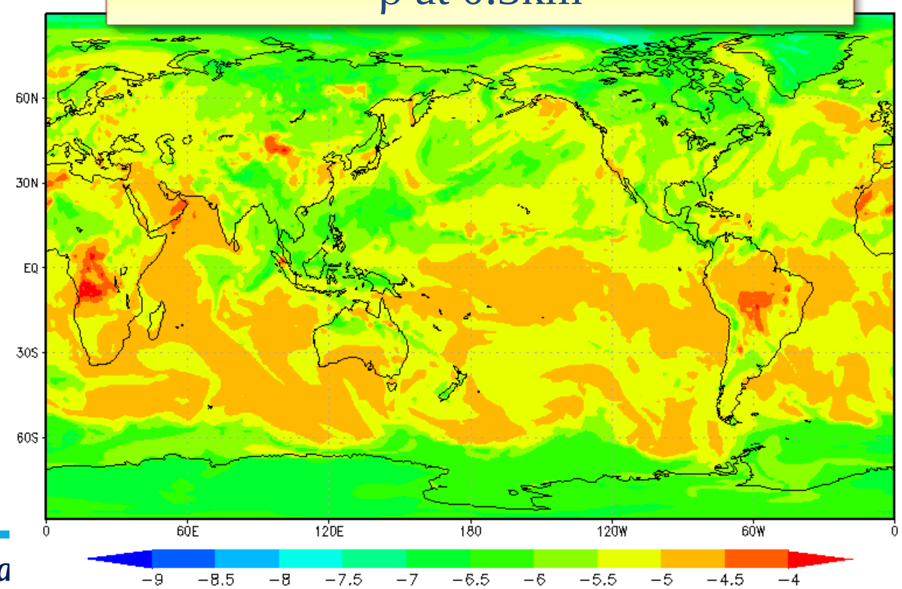
β at 16km



AOD of all aerosols



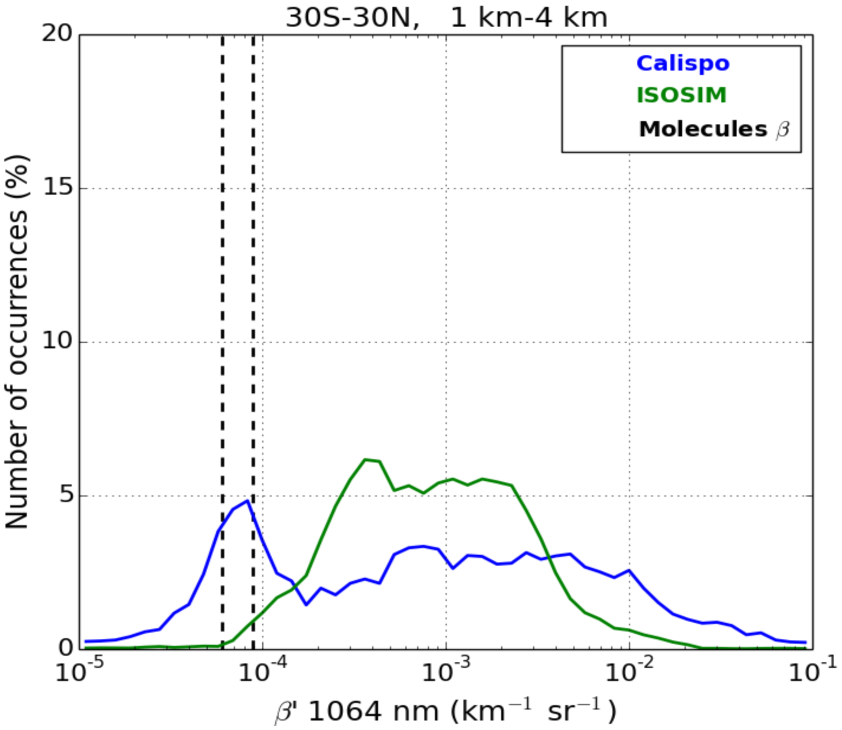
β at 0.3km

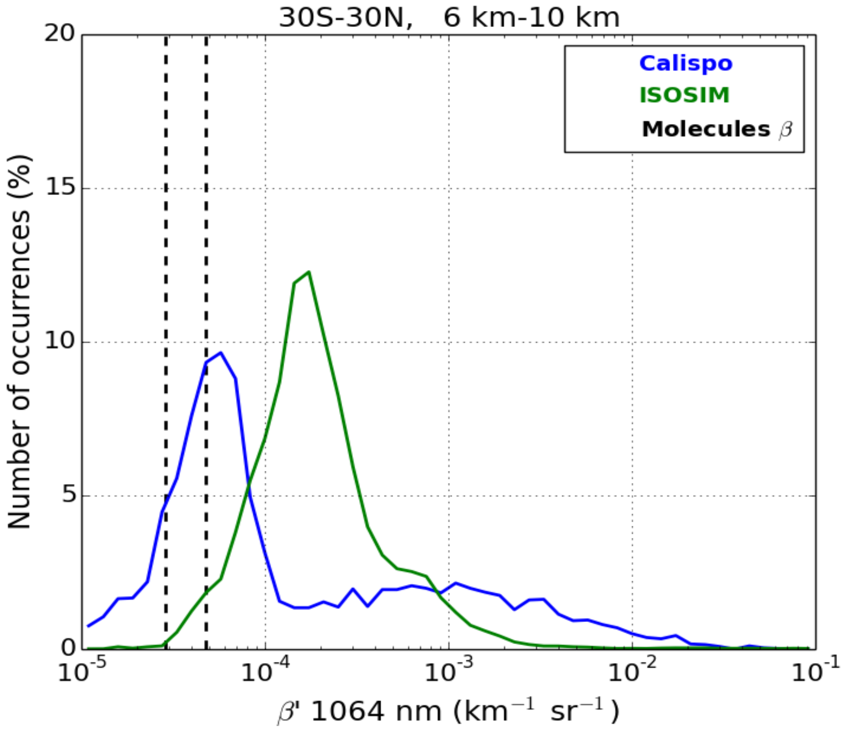


Preliminary results (latitude range: 30S-30N)

CALIPSO data have been horizontally averaged over 1000 km

- Reduce measurement noise and cloud impact
- Results are representative of aerosol attenuated backscatter





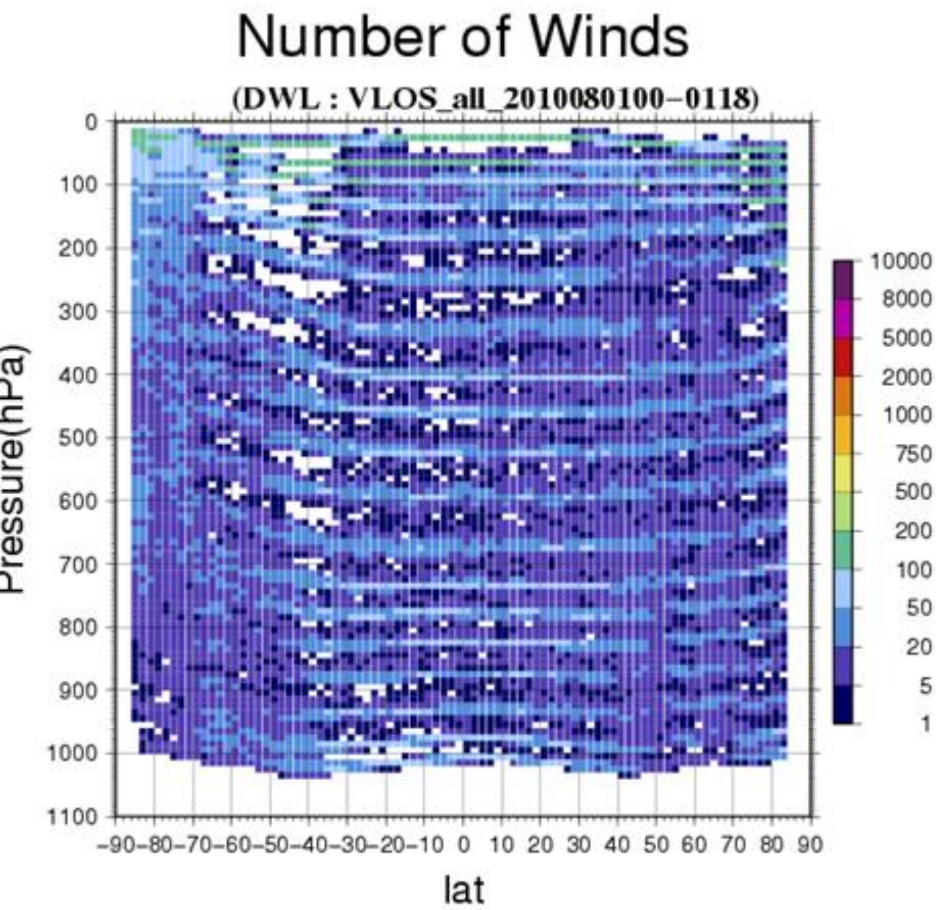
Similar work for cloud backscatter comparison is in progress.
CALIPSO data were obtained from the NASA LaRC Atmospheric Science Data Center (ASDC).

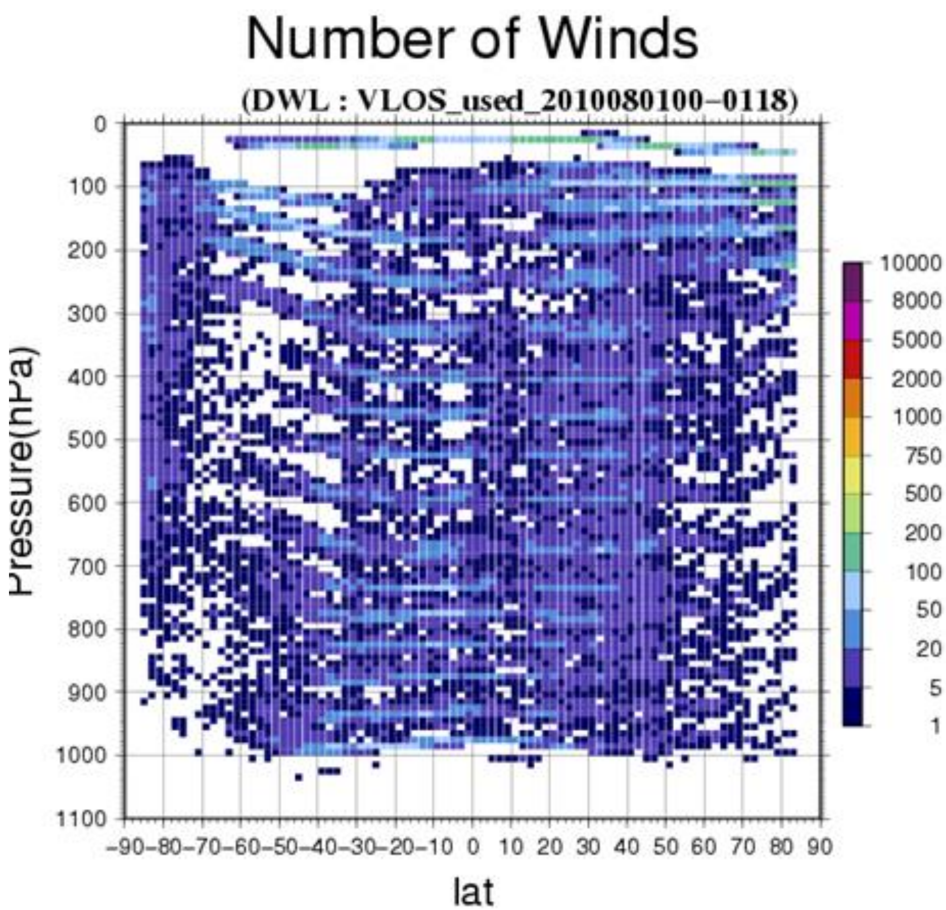
OSSE: SOSE approach

- Sensitivity Observing System Experiment (Marseille et al. 2008)
  - Pseudo-truth (PT) field is created by correcting first-guess based on adjoint sensitivity and assimilating real observations
    - PT field is consistent with obs and reduces forecast-errors
  - Simulation of existing observations is not necessary, unlike Nature-Run OSSE

- ISOSIM-L needs
  - PT winds
  - 3-dimensional aerosol
    - Generated by aerosol data assimilation cycle nudged with PT winds
      - the global aerosol model of JMA/MRI (MASINGAR; Tanaka and Chiba 2005)
  - 3-dimensional cloud
    - First-guess calculated through SOSE PT cycle

Number of DWL data before/after QC on August 1, 2010

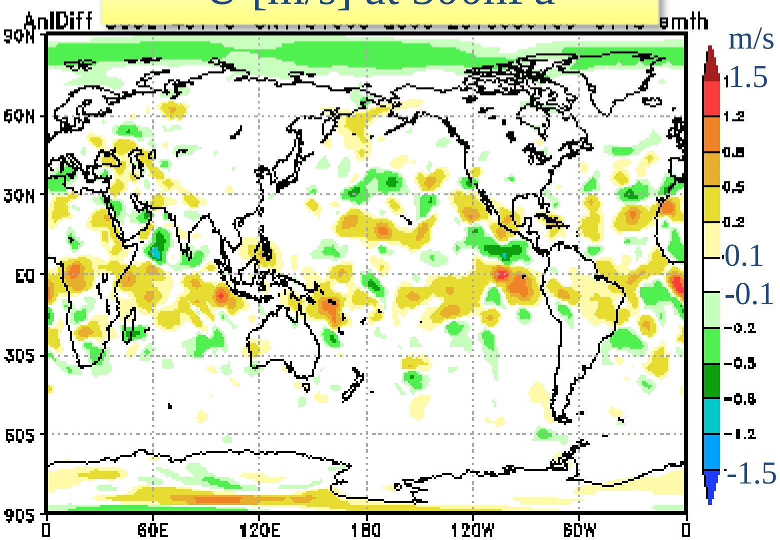




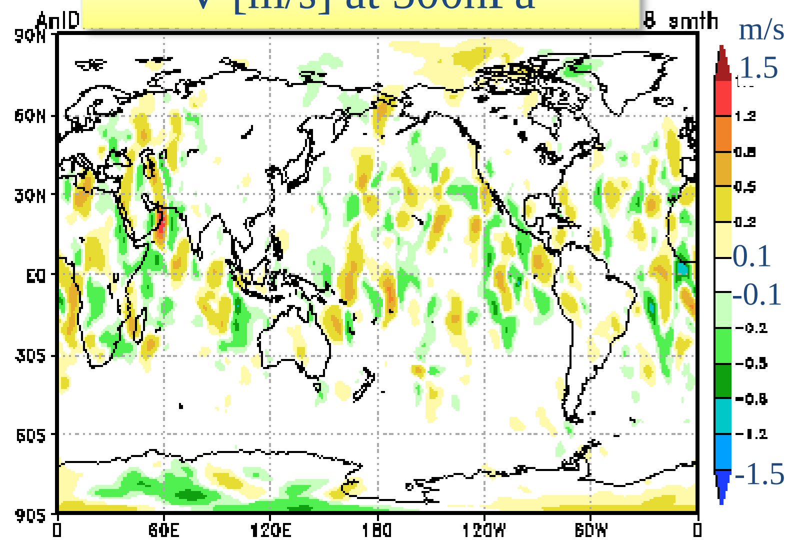
Integrated number of DWL data before/after QC at 12 UTC 1 Aug 2010.
1 pixel: 2degx2degx10hPa.

Analysis difference with DWL – without DWL (August 1, 2010)

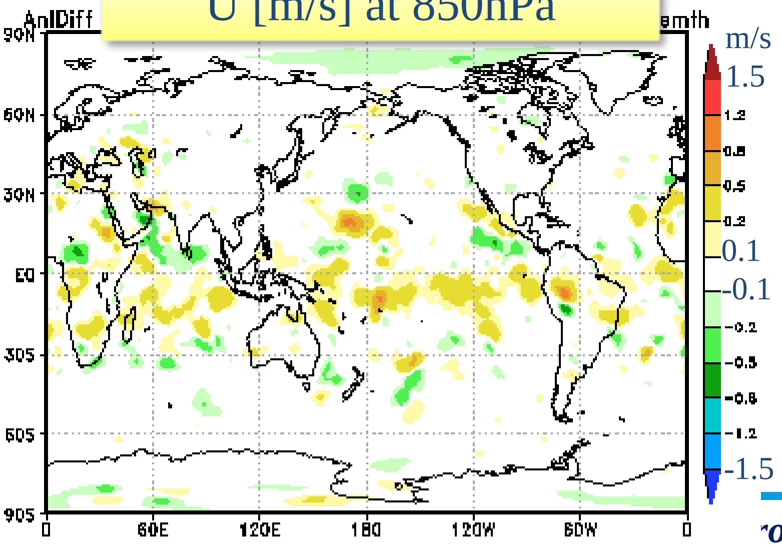
U [m/s] at 500hPa



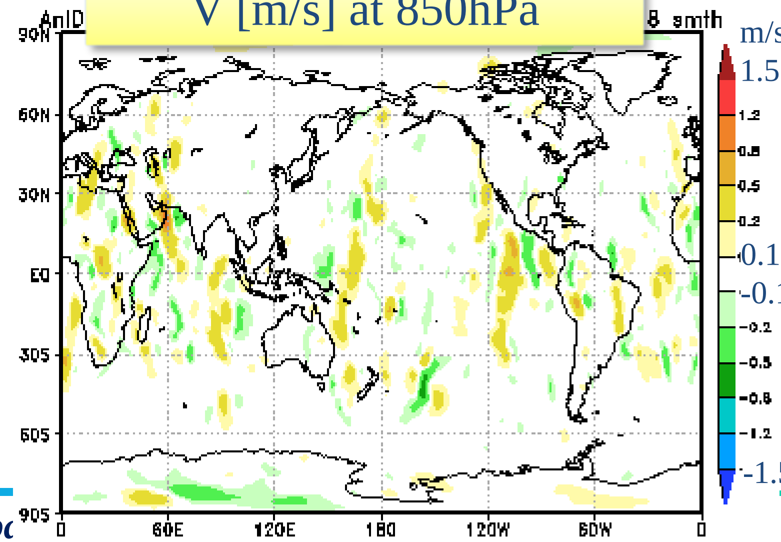
V [m/s] at 500hPa



U [m/s] at 850hPa



V [m/s] at 850hPa



Summary

Studies on the feasibility of Doppler lidar installed into super low altitude satellite were conducted in FY2013.

- **Mechanical, thermal, and power considerations for the satellite**
  - Two telescopes (Φ40cm) can be installed into a paylode (1.5x1x1(m^3)). Redundant laser needs more discussions.
  - 4 radiator panels (1.25 (m^2)/1 panel) is need from the consideration of the thermal waste (Total Power (only lidar) = 730W).
  - Solar array panel areas required for polar and low inclination orbits are 5.5 and 10.8 m^2, respectively from total power consumption.
- **2µm Laser design studies**
  - Although our laser simulation has a possibility that temperature dependency of a laser rod is small, both 1 OSC and MOPA lasers could operate at a target pulse energy of 125 mJ at a pulse repetition frequency of 30Hz.
  - Space qualified chiller cooling down to 173K is necessarily for 1 OSC laser. MOPA laser would be better than 1 OSC laser.
  - Total waste heat power for 2 lasers is 730W.

Summary

- **NICT and MRI are developing simulators to conduct "OSSE" with collaborating each other.**
  - NICT developed Doppler wind lidar simulator (ISOSIM-L) in FY2001. In order to simulate lidar signal using flexible lidar system parameters (integration time, multi directions (up to 4), multi satellite (up to 10) etc..) and 3D realistic atmosphere, Major changes of ISOSIM-L were done in FY2013.
  - ISOSIM-L simulated the lidar signal during from August 1 to August 30, 2010, and produced 3D LOS wind speed and errors (Horizonal: 100km x 100km, Vertical: 0.5, 1.0, 2km). Preliminary results were provided to MRI.
  - Aerosol/cloud backscattering coefficient calculated by ISOSIM suggested that ISOSIM overestimated aerosol/cloud backscattering coefficient. <u>We must improve how to calculate the backscattering coefficient. Improvement is ongoing.</u>
    - Ice clouds, turbulence, vertical wind...

Summary

- **NICT and MRI are developing simulators to conduct "OSSE" with collaborating each other.**
  - OSSE based on SOSE was constructed at MRI. MRI checked simulated OSSE data and evaluating data quality.
  - First one-month OSSE was conducted using simulated Doppler Wind lidar data. Preliminary OSSE results suggested that Doppler Wind lidar measurements impact at low latitudes.
    - Limited radiosonde and airborne measurements, limited wind information derived from indirect wind measurement.
  - After validation and improvement of ISOSIM-L, NICT will simulate one-month Doppler lidar wind measurements. After that, MRI will make one-month assimilation experiments, and evaluate impact on forecasts.

Thank you for your attention

Back Up

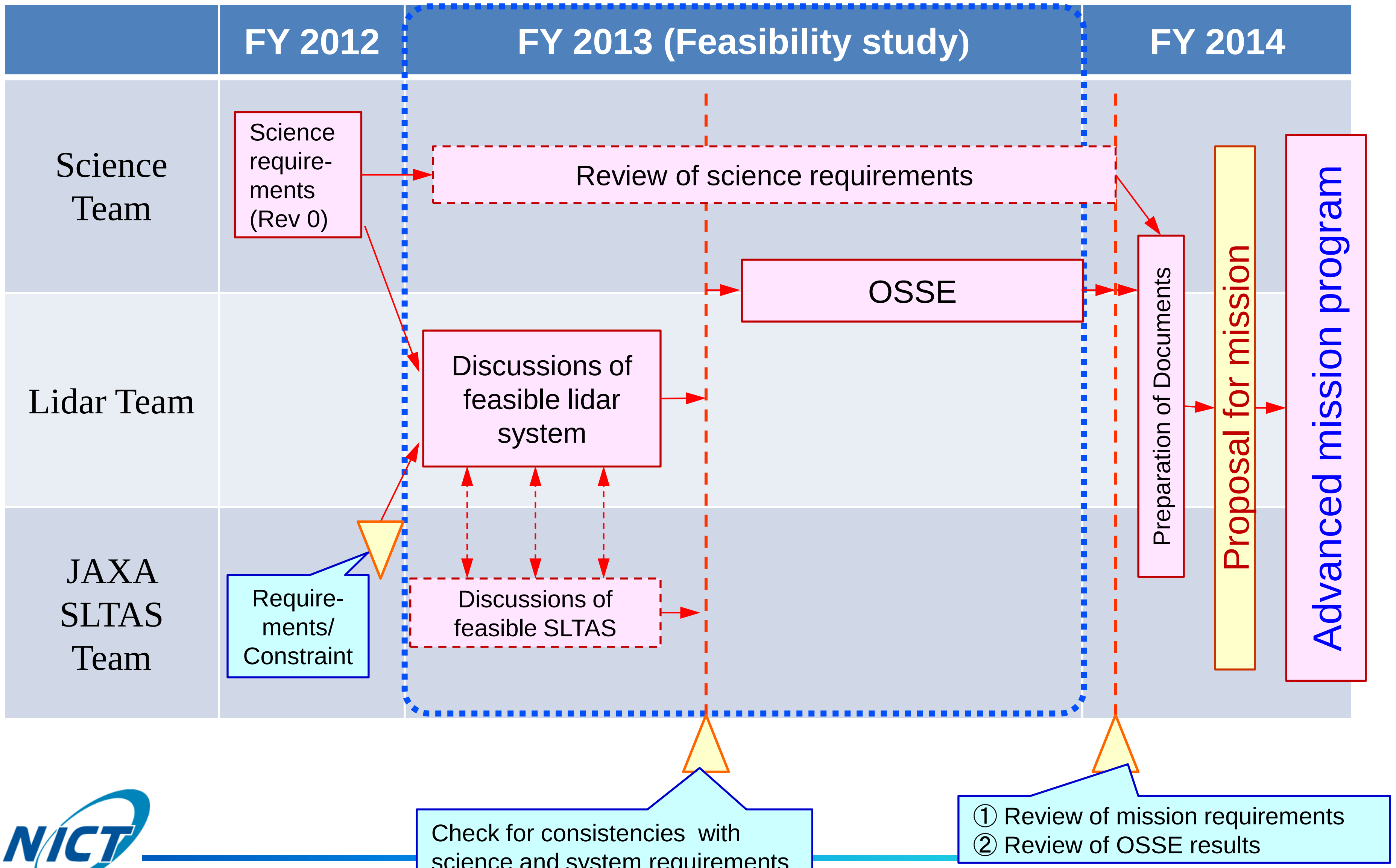
User requirements for horizontal wind measurement

wind profile	Applica-tion	Horizontal resolution (km)			Vertical resolution (km)			Observing Cycle (h)			Delay of Availability (h)			Accuracy (m/s)		
		Goal	B/T	T/H	Goal	B/T	T/H	Goal	B/T	T/H	Goal	B/T	T/H	Goal	B/T	T/H
U,V (LT)	Global NWP	15	100	500	0.5	1	3	1	6	12	0.1	0.5	6	1	3	5
U,V (HT)	Global NWP	15	100	500	0.5	1	3	1	6	12	0.1	0.5	6	1	3	8
U,V (LS)	Global NWP	15	100	500	0.5	1	3	1	6	12	0.1	0.5	6	1	3	5
U,V (LT)	High Res NWP	10	36.8	500	0.4	0.93	5	0.5	1.44	12	0.25	0.5	2	1	1.7	5
U,V (HT)	Regional NWP	10	36.8	500	1	2.2	10	0.5	1.44	12	0.25	0.5	2	1	2	8
U,V (LS)	Regional NWP	10	36.8	500	1	2.2	10	0.5	1.44	12	0.25	0.5	2	1	1.7	5

B/T: Breakthrough, T/H: Threshold

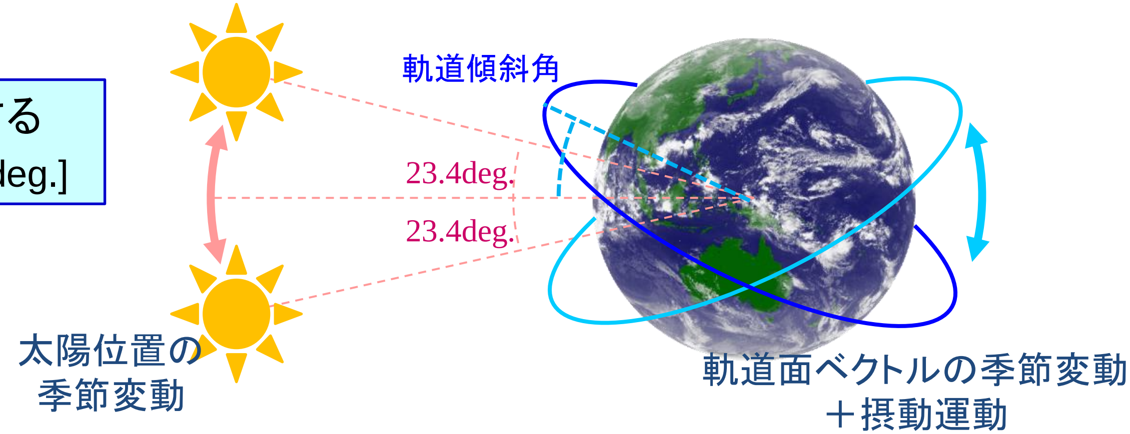
www.wmo-sat.info/lscar/variables/view/179

Schedule (FY 2013)



衛星システム/電力

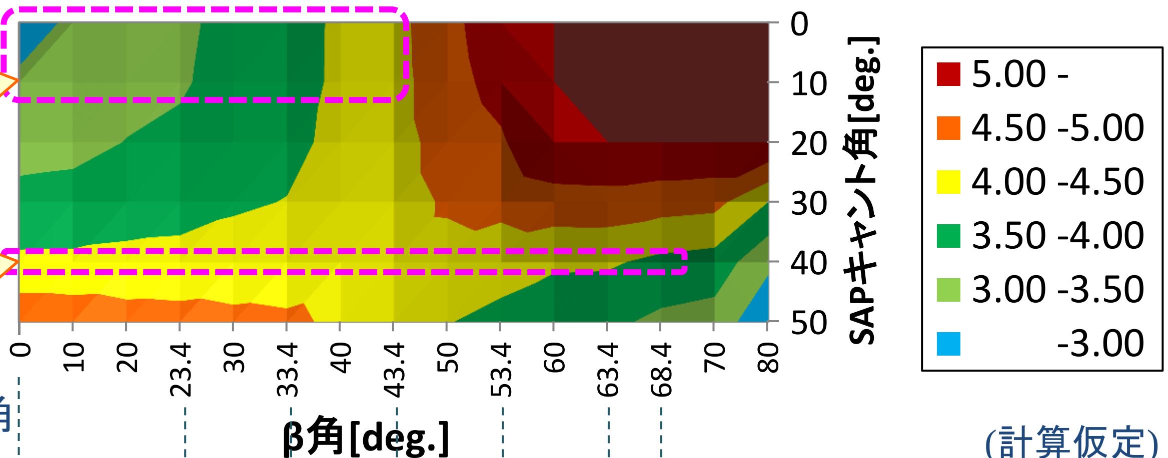
① [課題] 太陽光入射角βが変動する
※ 変動範囲： 0～(軌道傾斜角＋23.4)[deg.]



② 常に所要電力を発生できる
SAP幅＆SAPキャント角を求めた

傾斜角: 0~20deg.
→ 4.3m/翼、ｷｬﾝﾄ
~0deg.
（ケースB-1）

傾斜角: 30~45deg.
→ 4.3m/翼、ｷｬﾝﾄ
40deg.
（ケースB-2）



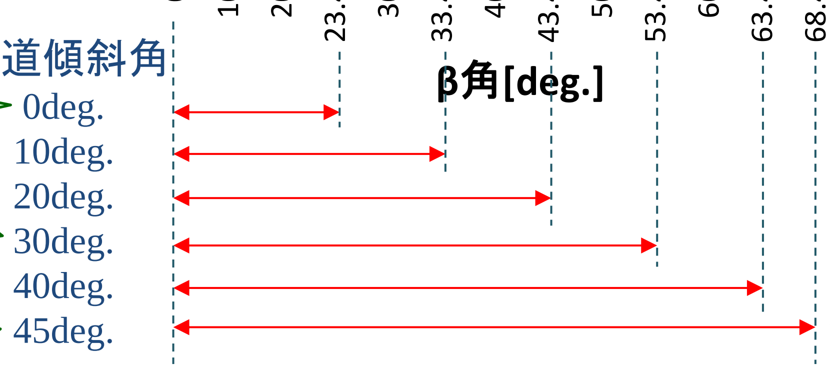
必要な
SAP幅[m/翼]

軌道傾斜角

SAPは最小

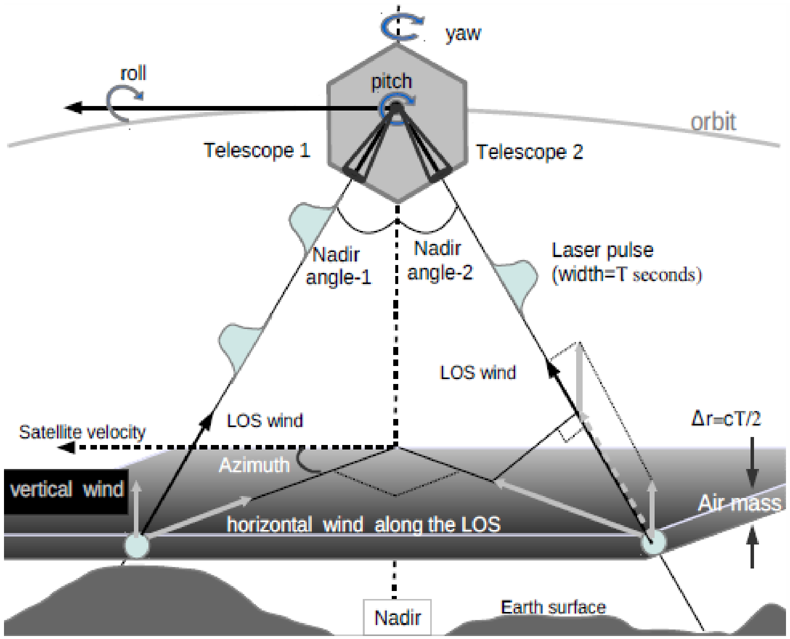
一番大質量を
運べる

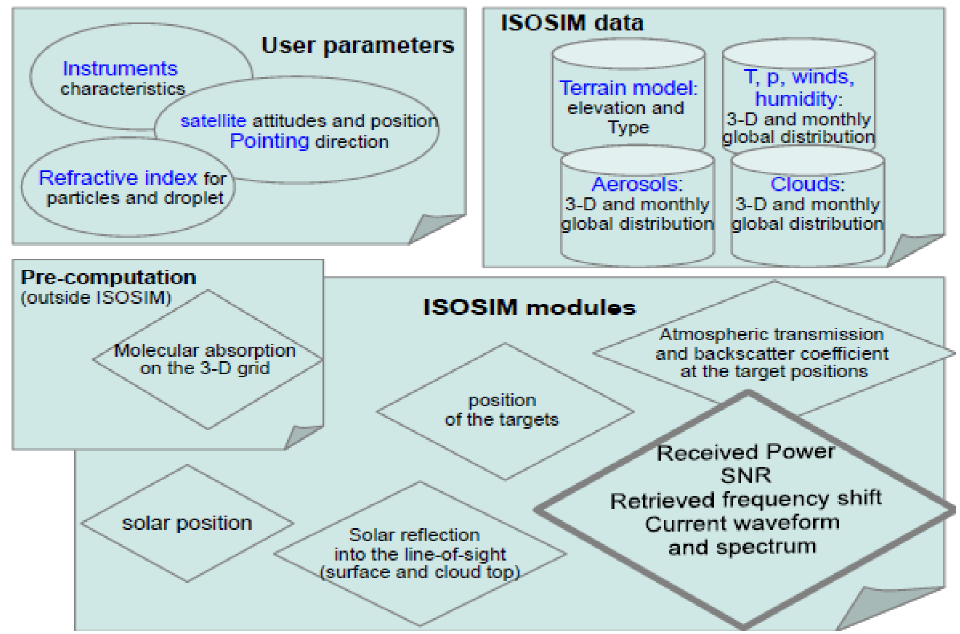
日本がほぼ全
部見える



(計算仮定)
※ 太陽光照度: 1300W/m²(最小)
※ 光電気変換効率: 25%(3接合セル)
※ 衛星のX方向寸法: 2.5m
※ キャント角

Lidar simulator (ISOSIM-L)





- Integrated Satellite Observation SIMulator for a spaceborne coherent Doppler lidar (ISOSIM-L) was developed to simulate for wind measurement from space at NICT.
- Objectives in the development of the ISOSIM-L are…,
  - Study performances of a spaceborne coherent Doppler lidar with an eye-safe laser, fixed or scanning receiver, motion and jitter of a moving platform for various atmospheric conditions.
  - Evaluate the random error, sampling produced by laser beam and the configuration of the receiver, and bias in a non-turbulent atmosphere and in a turbulent atmosphere.
  - Produce simulated wind data for the Observing system simulation experiment (OSSE)
  - Collaborate with other universities and research institutes to combine the ISOSIM-L and the OSSE.

LOS wind retrieval

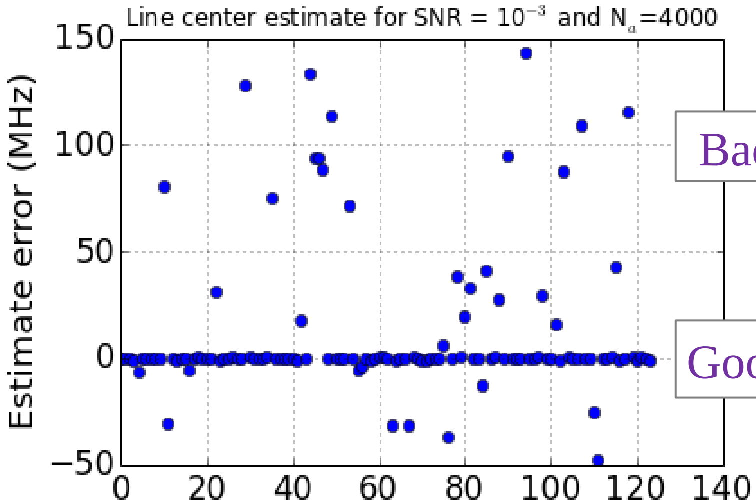
- Power spectrum is derived from Fourier analysis (resolution of 1.56 MHz in this analysis)
- The frequency of the line center is found using a standard Likelihood method (Rye et al., (1993), Frehlich et al. (1994))
  - The spectrum amplitude is smoothed using a filter defined with the observational characteristics (SNR, laser pulse width)
  - The line center estimate has the maximum amplitude
  - The estimate resolution is that of the spectrum (1.56 MHz)
- Spectrum sub-resolution is achieved using 2nd order poly fit of the line amplitude at the selected frequency and its two adjacent points.

Rye, B. and Hardesty, R.: Discrete spectral peak estimation in incoherent backscatter heterodyne lidar. I. Spectral accumulation and the Cramer-Rao lower bound, Geoscience and Remote Sensing, IEEE Transactions, 31, 16–27, doi:10.1109/36.210440, 1993

Frehlich, R. G. and Yadlowsky, M. J., Performance of mean-frequency estimators for Doppler radar/lidar, J. Atmos. Ocean. Technol, 11, 1217:1230, 1994

Performance of the line center estimates algorithm based on repeated simulations

B = 200 MHz (Ts = 2.5 ns), Spectrum resolution = 1.56 MHz (M=256),
Pulse FWHM = 200 ns (~0.96 MHz)
Random line frequency = 50 +/- 5 MHz



Bad estimates

Good estimates

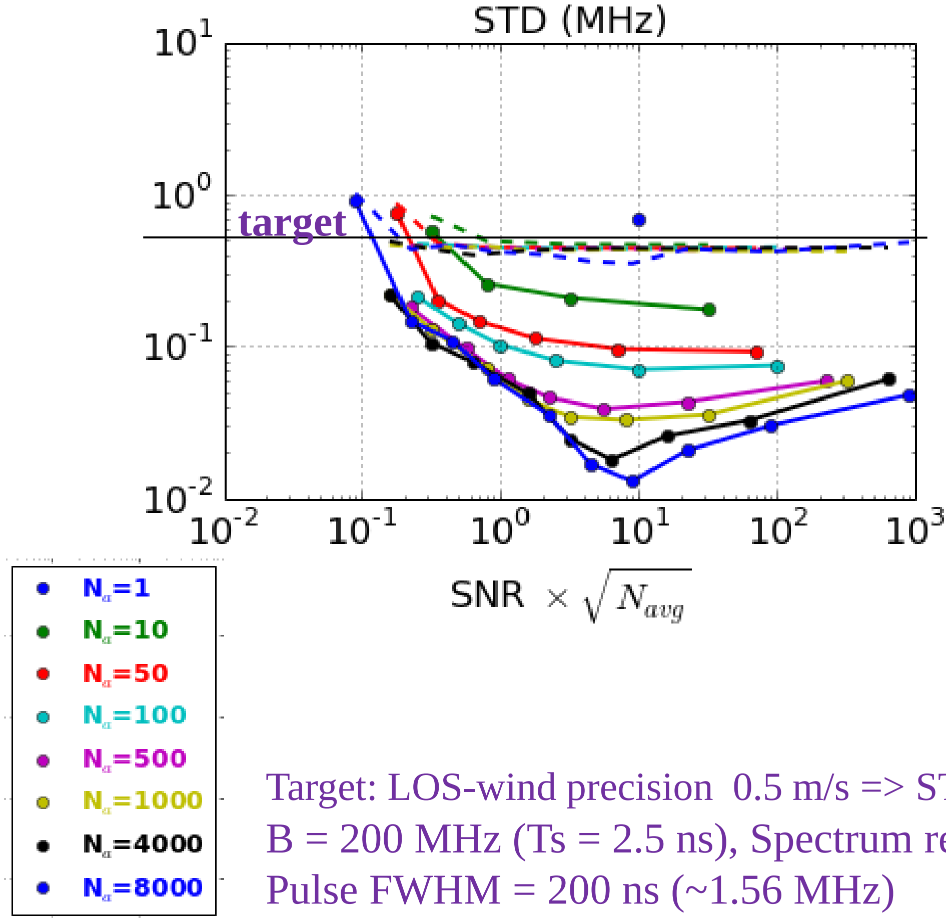
Retrieval simulation index

- LOS wind estimates are characterized by:
  - The number of bad estimates (noise peak selected instead of the atmospheric line)
  - The spread of good estimates is related to the measurement precision

Only observations with a small probability of bad estimations are used, typically smaller than 10%.

LOS wind precision

Dashed line: estimation without line-center fit
Full line: estimation with line center fit

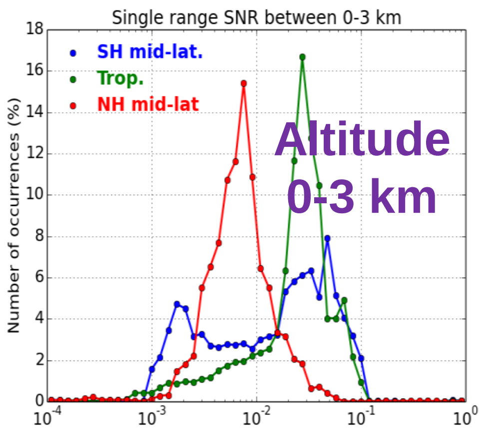


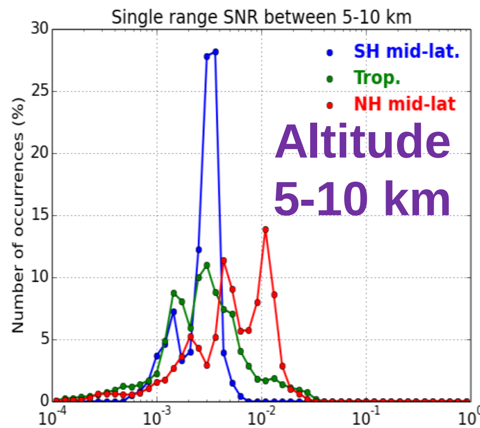
- *Na* is the number of averaged data.
- For *Na>10* and *Na*sqrt(SNR)< 10*, the measurement precision depends on sqrt(Na) and SNR.
- The targeted LOS-wind precision (0.5 MHz at λ=2050 nm) is achieved for SNR>10^{-3} (*Na=8000*)
- The polynomial fit significantly improves the line center estimate precision.
- For *SNR>10* and *Na>1000*, the wind precision slightly increases because of the errors from the line center poly. fit.

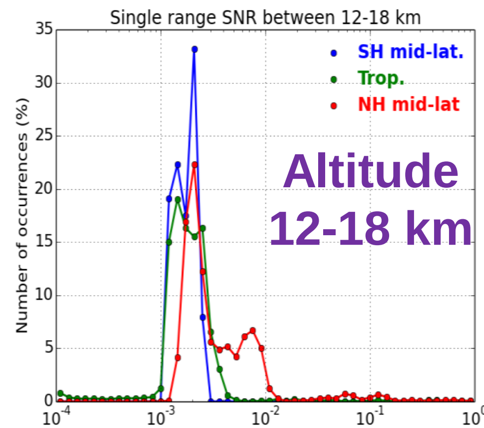
Target: LOS-wind precision 0.5 m/s => STD = 0.5 MHz at λ=2051 nm
B = 200 MHz (Ts = 2.5 ns), Spectrum resolution = 1.56 MHz (M=256),
Pulse FWHM = 200 ns (~1.56 MHz)

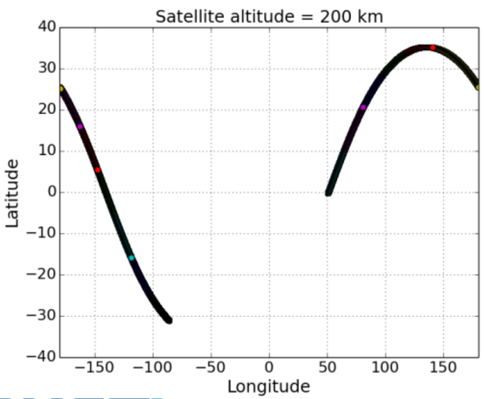
Calculated SNR using the simulator ISOSIM-L

λ=2051 nm
Telescope diameter = 40 cm, Pulse energy = 125 mJ, Pulse FWHM = 200 ns, PRF = 30 Hz
B = 200 MHz (Ts = 2.5 ns), Spectrum resolution = 1.56 MHz (M=256, T=640 ns)
Orbit height =220 km, Nadir angle = 35 deg.



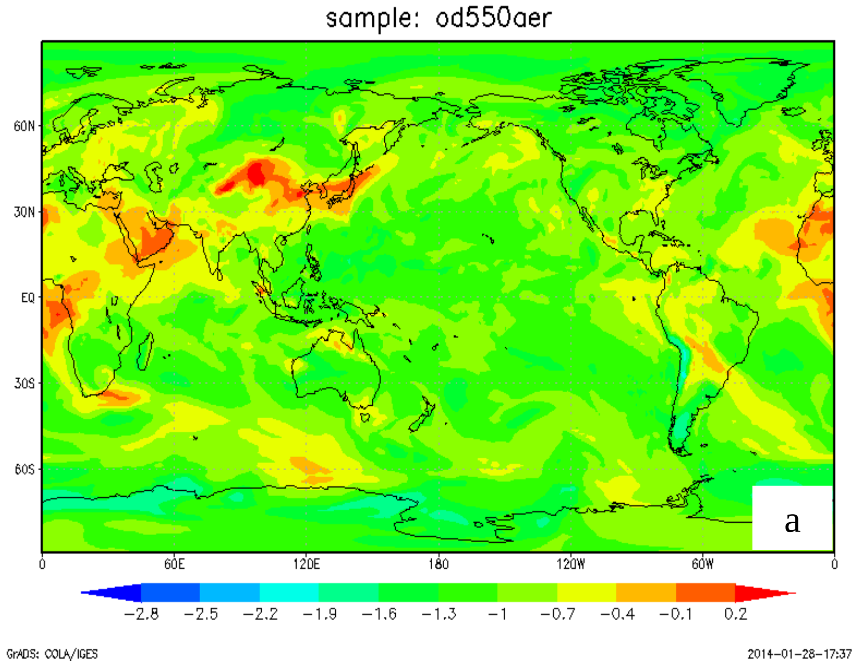


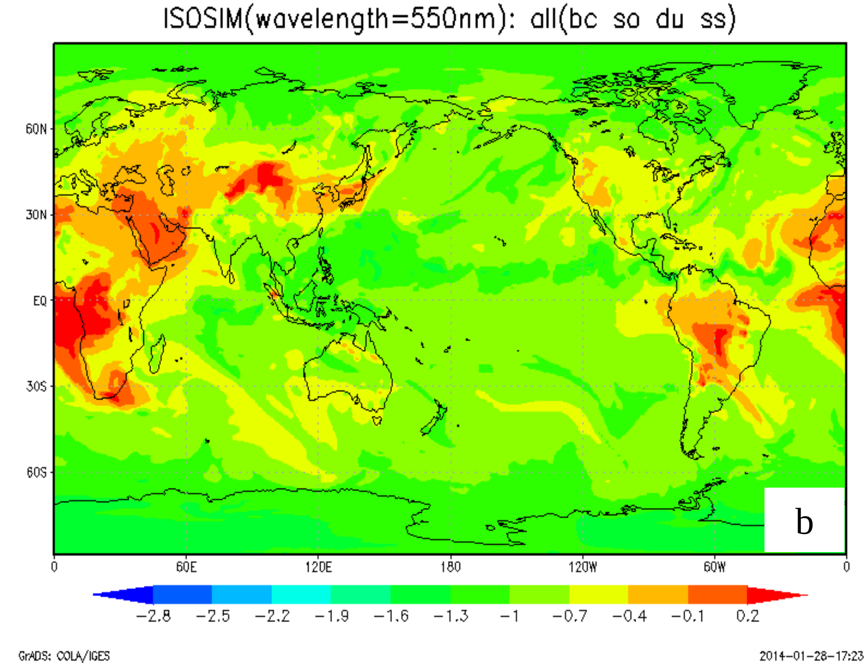


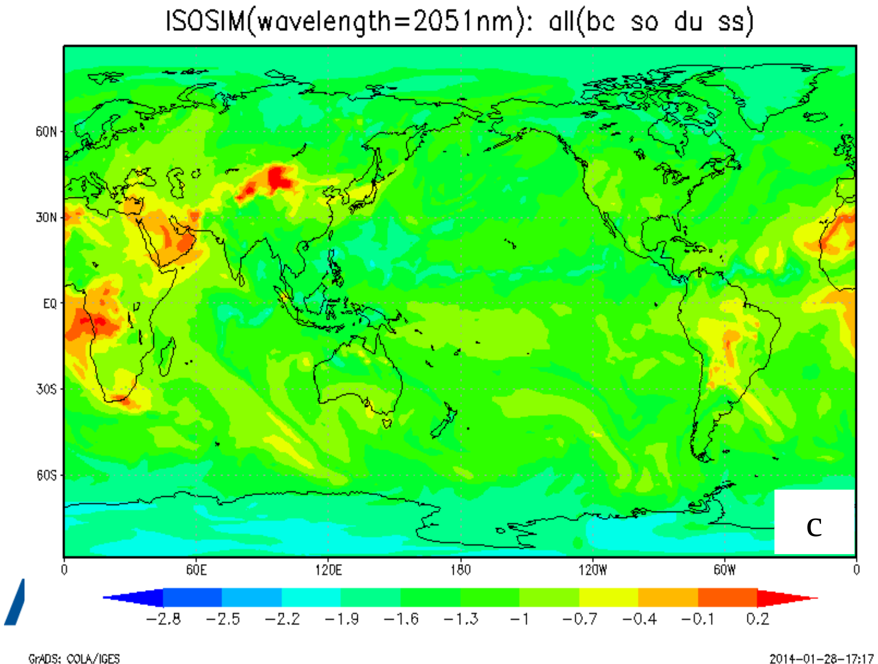


- Most of the observations lie in the suited SNR range (SNR>10^3 for bad estimates < 10%)
- Need Na>4000 in the **free/upper troposphere** (horizontal resolution 50-100 km, vertical resolution 1 km)
- **In the lower troposphere,** good observations can be achieved with Na<100 (e.g. vertical resolution 100 m and horizontal resolution 10 km)

These results have to be taken with precautions because the model validation is still in-progress.

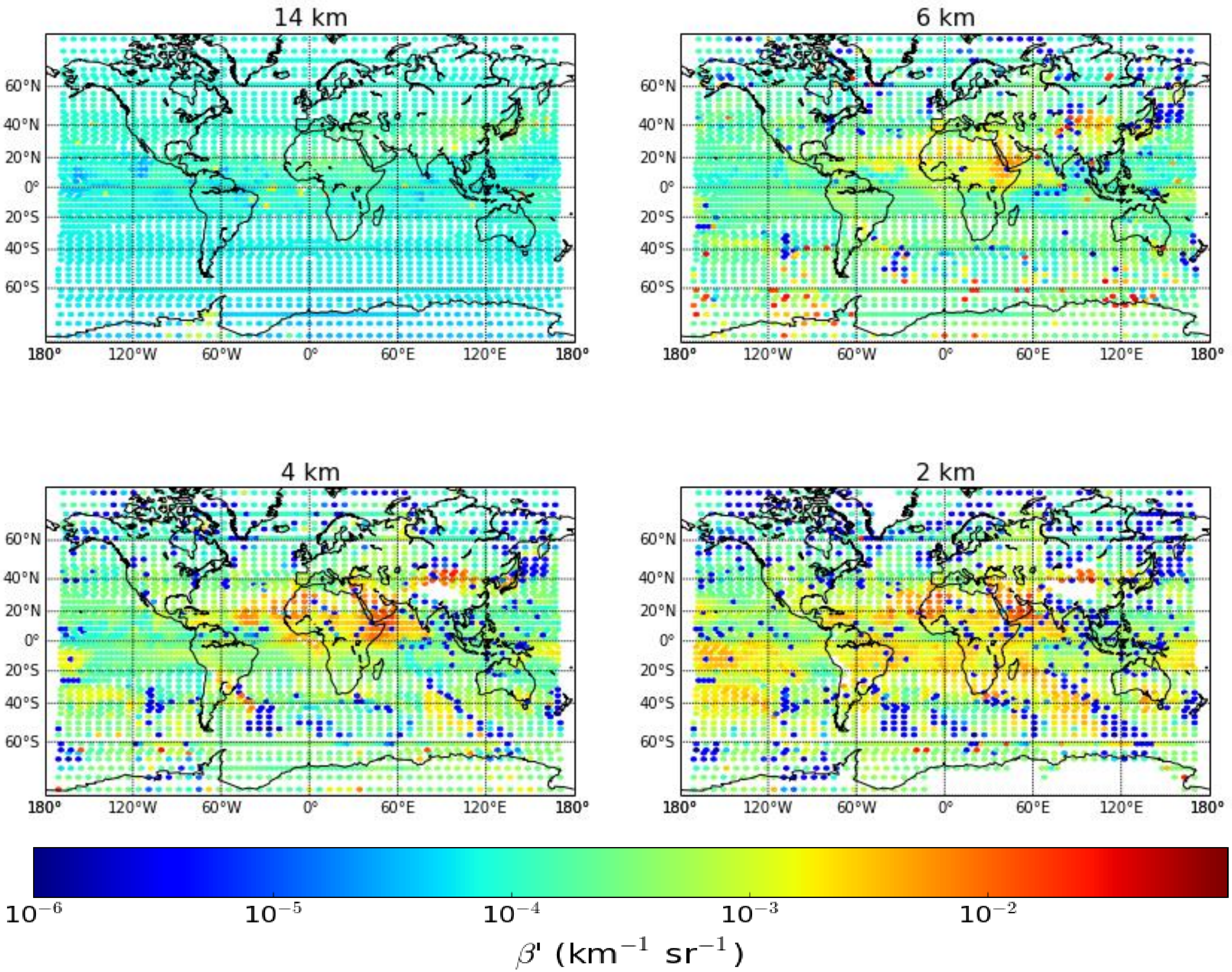




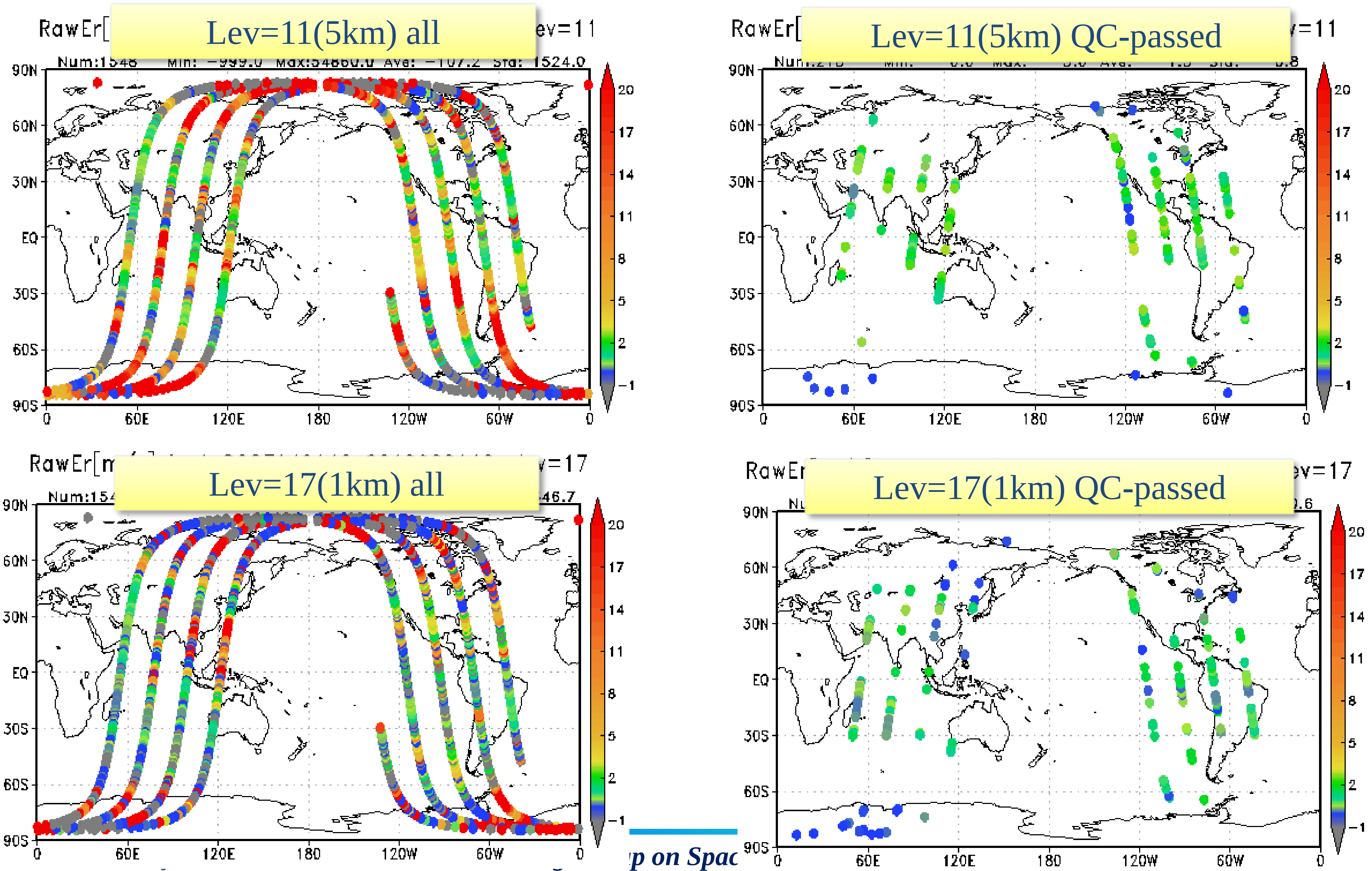


Comparison of AOD
Aerosol data (00UT, August 1, 2010) produced by MASINGAR
a.MRI result at 550nm
b.ISOSIM-L result at 550nm
c.ISOSIM-L result at 2051nm

ISOSIM-L attenuated backscatter at 1064 nm and Nadir direction



DWL obs.error [m/s] before/after QC at 12 UTC 1 Aug 2010

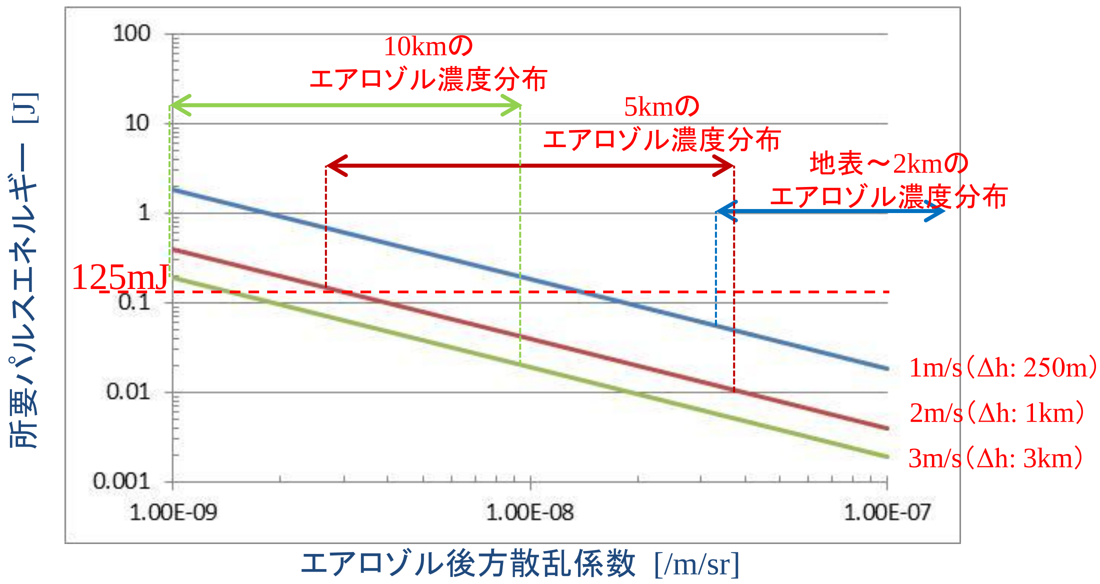


Summary

- **NICT and MRI are developing simulators to conduct "OSSE" with collaborating each other.**
  - NICT developed Doppler wind lidar simulator (ISOSIM-L) in FY2001. In order to simulate lidar signal using flexible lidar system parameters (integration time, multi directions (up to 4), multi satellite (up to 10) etc..) and 3D realistic atmosphere, Major changes of ISOSIM-L were done in FY2013.
  - ISOSIM-L simulated the lidar signal during from August 1 to August 30, 2010, and produced 3D LOS wind speed and errors (Horizonal: 100km x 100km, Vertical: 0.5, 1.0, 2km). Preliminary results were provided to MRI.
  - Aerosol/cloud backscattering coefficient calculated by ISOSIM were compared with 550-nm AOD calculated by MRI and CALIPSO data. The comparison suggested that ISOSIM overestimated aerosol/cloud backscattering coefficient. We must improve how to calculate the backscattering coefficient. Improvement is ongoing.
    - Ice clouds, turbulence, vertical wind...

2.2.1 センサ検討結果

回線計算条件：
A) AT方向100km で**風速が一様**、
B) エアロゾル濃度 10^{-9} /m/sr – 10^{-7} /m/sr（エアロゾルの濃度は一ケタ近くばらつくため）
C) レーザの視線方向は 30度（可能な限り視線方向距離を減らすため）
D) 上のエアロゾル条件ごとに精度、1m/s @地表面、 2m/s@5km、3m/s@10km（風速精度@地上高度）に必要なパルスエネルギーを求めた。
E) 観測波長は2um。



パラメータ	値
コヒーレントライダ全受信効率	20 %
望遠鏡有効開口	40 cm
検出帯域幅	200 MHz
パルス繰返し	20 Hz
積算時間	14 sec
軌道高度	220 km
offnadir 角	30deg

結論として、対流圏内で、かつAT進行中に風速変化がないという前提であれば、対流圏下層における**125mJでの回線計算は要求値を満たす**。

実際の風向風速値は一定ではないことから、以下の**2点が課題**として残る。

① １視線計測する140ショット (領域100km)で風速変化が大きい場合に積算効果が得られるのか？

② ドップラーシフトについて高い検出確率が得られるか？

Research framework of collaboration

Study on SLATS-borne Doppler lidar
JAXA Y. Satoh, S. Yamakawa

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