National Institute of Information and Communications Technology

Working Group Meeting on Space-based Lidar Winds

(February 7, 2018, NOAA David Skaggs Research Center, Boulder CO, US)

Recent activities of coherent Doppler Wind Lidar at NICT

S. Ishii[a], **A. Sato**[b, a], **M. Aoki**[a], **K. Akahane**[a], **S. Nagano**[a], **K. Mizutani**[a], **H. Iwai**[a], **K. Okamoto**[c, a], **P. Baron**[a], **S. Ochiai**[a], **and M. Kubota**[a]

a. National Institute of Information and Communications Technology

b. Tohoku Institute of Technology

c. Japan Meteorological Agency / Meteorological Research Institute

Outline

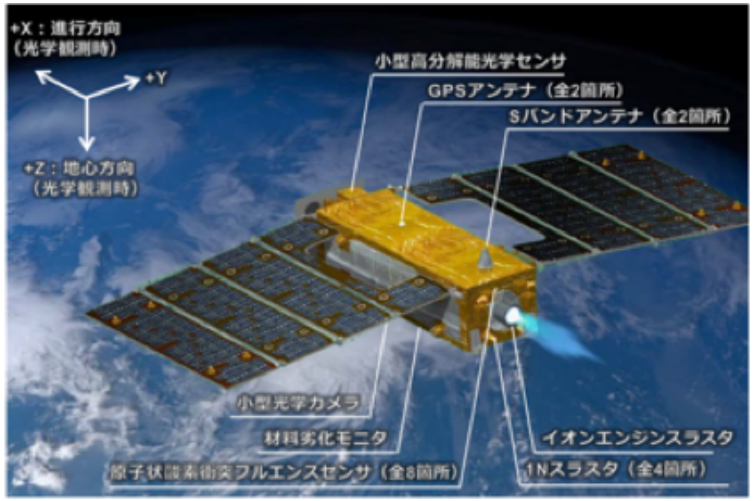
- Background and Objective
- Concept of future space-based Doppler Wind Lidar
- Development of high pulse-energy 2-μm laser
- Recent activities at NICT
- Summary

Background and Objective

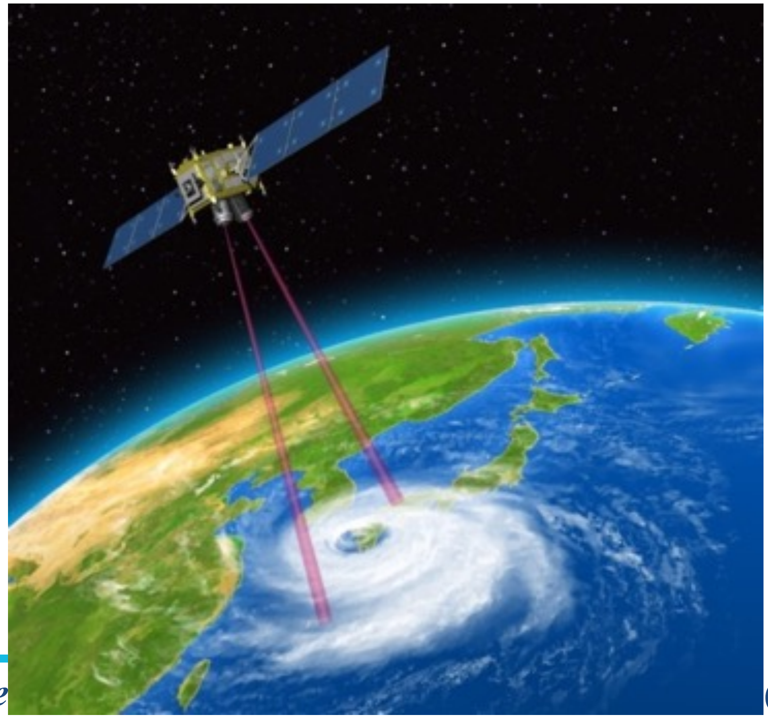
- Background
  - Global wind profile observation is essential to NWP. Current space-based observing systems are unbalanced toward temperature- and water-vapor-related measurements in comparison with wind measurements.
  - Space-based Doppler wind lidar (DWL) is one of promising candidate to fill the gap
  - ESA is planning to launch the first space-based DWL Aeolus for global wind profile observations.
- Objectives of this study
  - Development of a reliable stable single-frequency 2-μm pulse laser for DWL
  - Demonstration of the 2-μm pulse laser meeting requirements for a future space-based coherent DWL

Concept of super-low-altitude-satellite-based DWL

	Super Low Altitude space-borne Coherent Doppler Wind Lidar
Orbital altitude Orbit	220 km Polar orbit / Low-inclination orbit
Transmitter	2-μm pulse laser (125 mJ, 30 Hz)
Receiver	Heterodyne detection 0.4 m (primary mirror) x 2
Target horizontal resolution	<100 km
Target vertical resolution	Altitude 0-3 km: <0.5 km Altitude 3-8 km: <1 km Altitude 8-20 km: <2 km
Nadir angle	~35 degree
Looking angle	45 and 135 degrees
Target horizontal wind	-100~100 m/sec



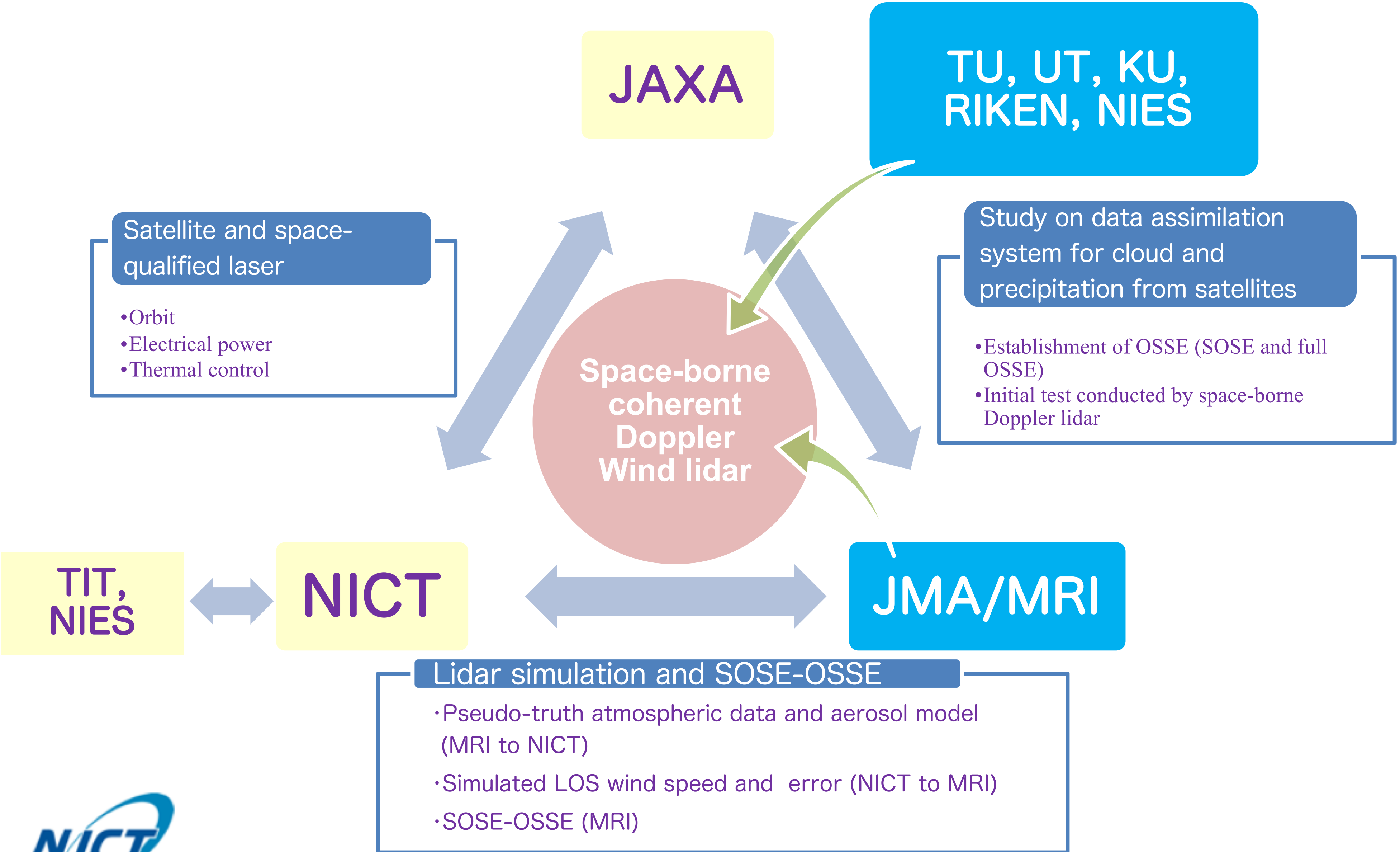
http://www.jaxa.jp/press/2017/10/files/20171027_h2af37_j.pdf



Super Low Altitude Test Satellite

- December 23, 2017: Launch
- Launch – 3 month: Check
  - Descending: 643 km x 450 km => 392-km circular orbit
- 3 month -
  - Descending: 392 km => 268 km circular orbit
- 15 month - 21 month
  - Keep orbital altitude
  - Ion engine
  - Descending: 392 km => 268 km circular orbit

Collaboration framework for space-borne Doppler lidar



Development of single-frequency high pulse-energy 2-μm laser

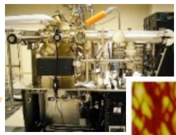
2μm semiconductor laser

2μm optical fiber amplifier

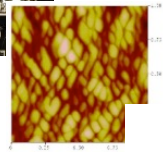
2μm single-frequency high pulse energy laser

2μm Quantum-dot laser

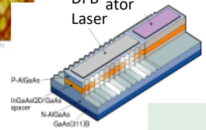
NICT



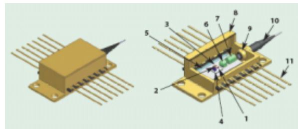
PDLに設置されている分子線
エピタキシー装置



分子線エピタキシー装置を用いて
作成された量子ダッシュ構造

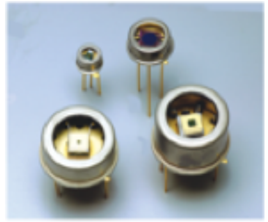


量子ドットレーザ試作

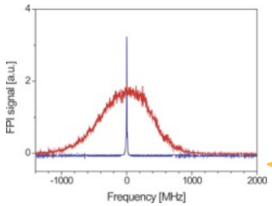


2μm Quantum-dot laser
(pigtail, Future)

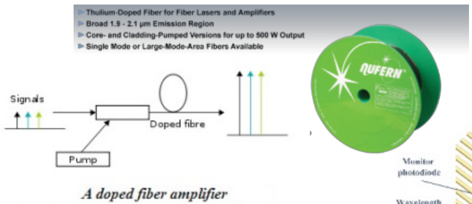
2μm detector
(Future)



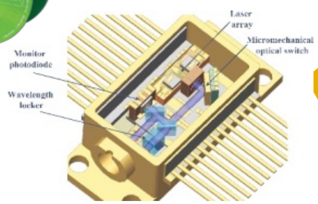
Narrow line width, high power, high stability



2μm optical fiber amplifier

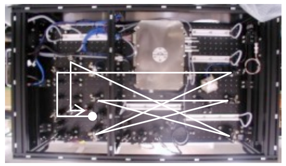


NICT



2μm Quantum-dot laser + AMP
(pigtail, Future)

2μm pulse laser

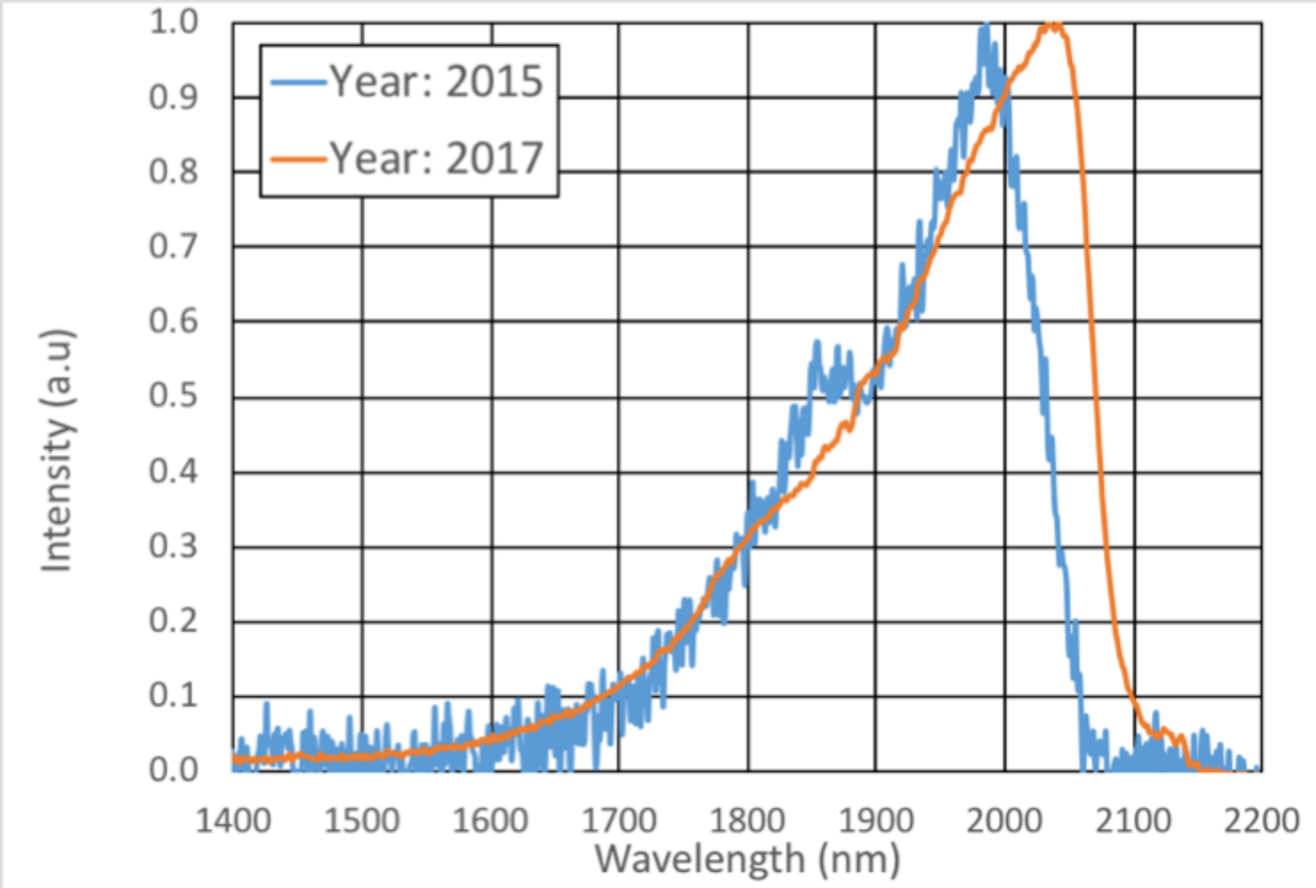


NICT, TIT

Commercial detector (non space -qualification

NICT

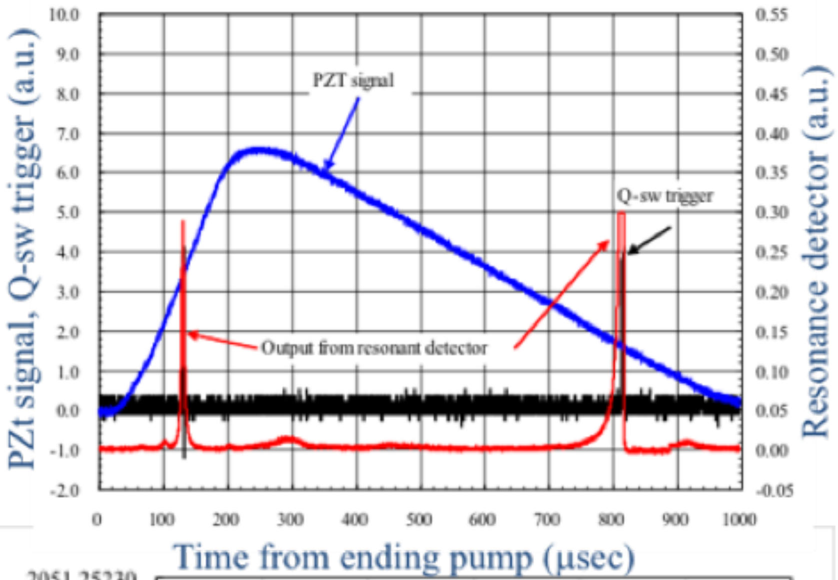
Development of 2-μm semiconductor laser for single-frequency laser

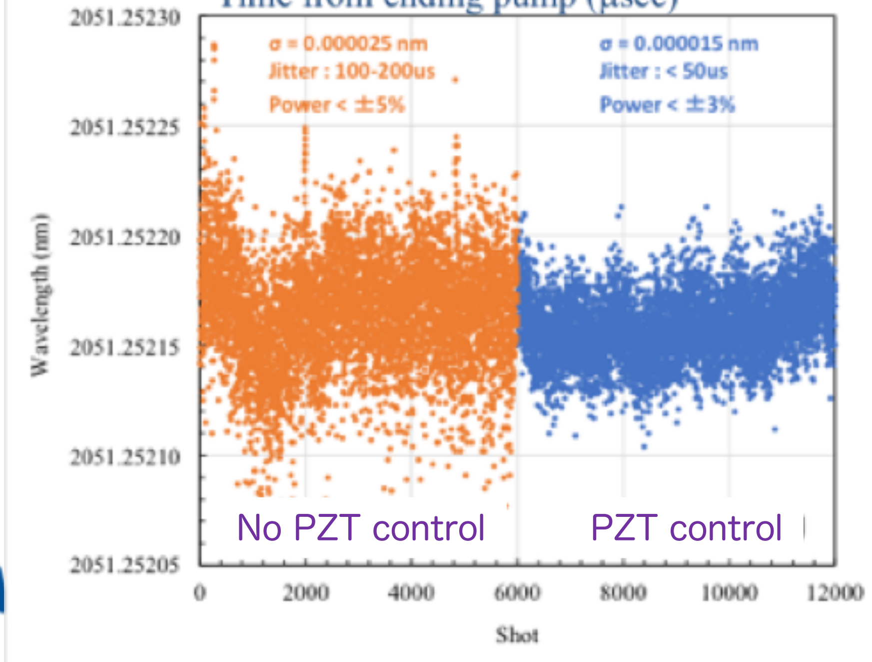


- Highly-stacked InAs quantum-dot layer for 2-μm laser
- Demonstration at 2-μm
- Next step
  - High output power
  - Narrow linewidth

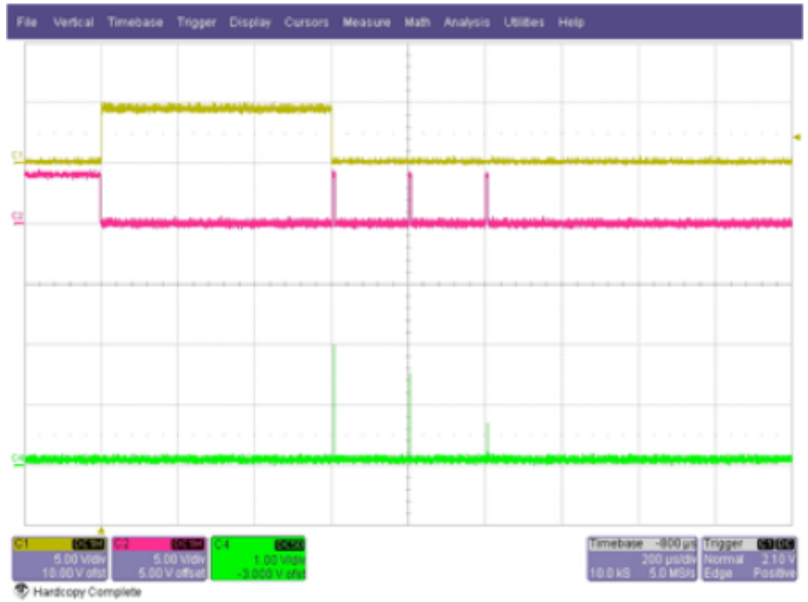
Development of electrical circuit for Laser cavity control

Updating of control circuit for Ramp and fire

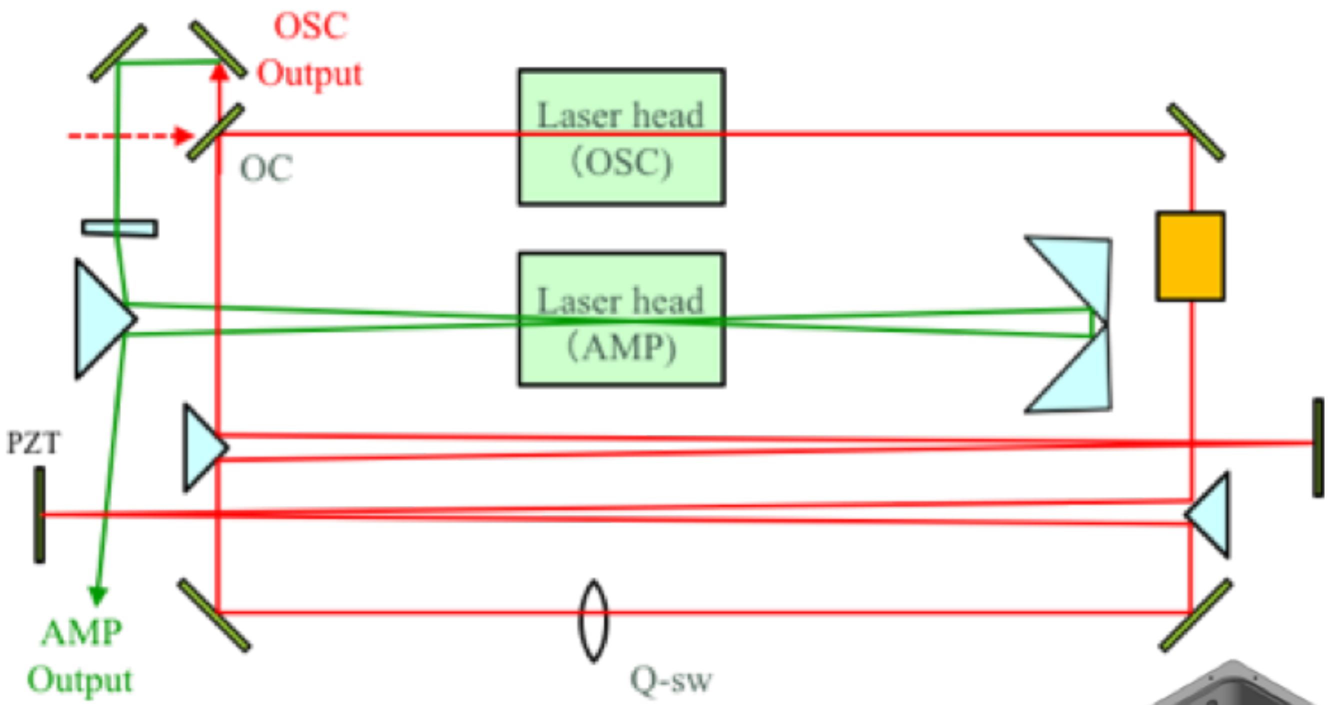


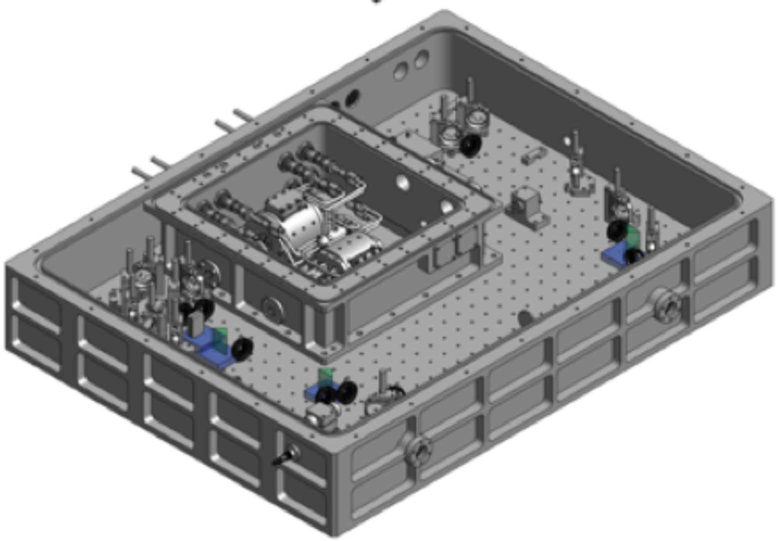


Time control for Q-switching for multi pulses



New 2-μm ring laser

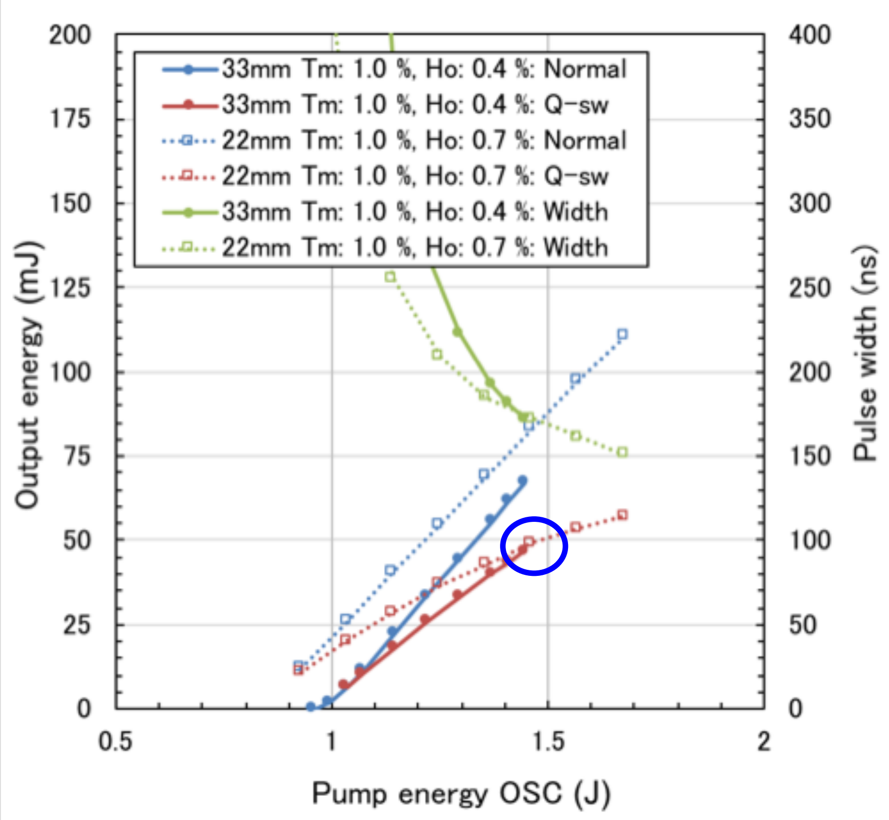


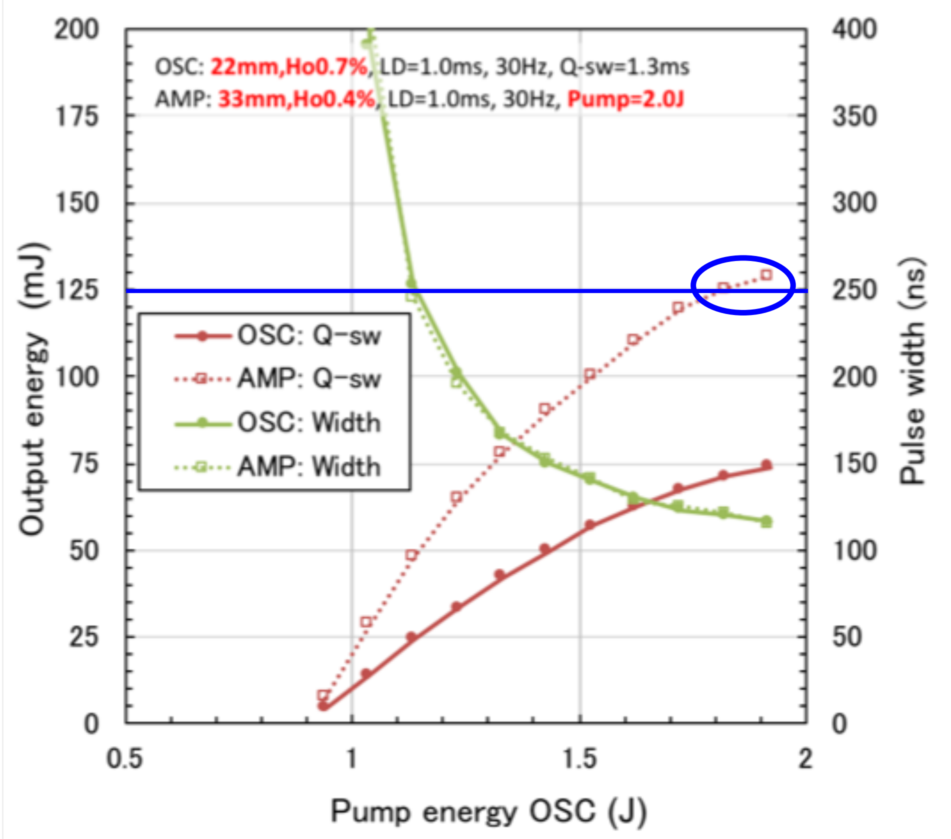


Design concept

- Simple ring laser design
- Robust and compact ring laser design
- Easy optical alignment

Lasing characteristics of 2-μm ring laser





OSC (Test I)
Laser rod: Φ4mm x 33 mm
Tm: 1.0 %, Ho: 0.4 % => 47 mJ at 30 Hz
OSC (Test II)
Laser rod: Φ4mm x 22 mm
Tm: 1.0 %, Ho: 0.7 % => 50 mJ at 30 Hz

OSC
Laser rod: Φ4mm x 22 mm
Tm: 1.0 %, Ho: 0.7 %
AMP
Laser rod: Φ4mm x 33 mm
Tm: 1.0 %, Ho: 0.4 %

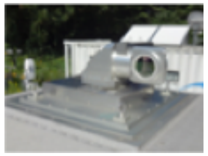
Comparison of high pulse-energy 2-μm laser

FOM	L: 33mm Ho: 0.4% PRF: 30Hz OSC: 1.5J	L: 33mm Ho: 0.4% PRF: 50Hz OSC: 1.5J	L: 22mm Ho: 0.4% PRF: 30Hz OSC: 1.5J	L: 22mm Ho: 0.7% PRF: 30Hz OSC: 1.5J	L: 22mm Ho: 1.0% PRF: 30Hz OSC: 1.5J
Single pulse AMP: x1.5 Single pulse AMP 1.5倍（1.5J）を仮定	× FOM: 0.087 (64mJ, 50cm)	○ **FOM: 0.113 (64mJ, 50cm)**	○ **FOM: 0.110 (80mJ, 50cm)**	◎ **FOM: 0.116 (85mJ, 50cm)**	× FOM: 0.085 (62mJ, 50cm)
	PWR: 240 W WP: 0.8%	PWR: 400 W WP: 0.8%	PWR: 240 W WP: 1.0%	PWR: 240 W WP: 1.1%	PWR: 240 W WP: 0.8%
Single pulse AMP: x2.0 Single pulse AMP 2.0倍（2.0J）を仮定	× FOM: 0.104 (76mJ, 50cm)	○ **FOM: 0.135 (76mJ, 50Hz, 50cm)**	○ **FOM: 0.129 (94mJ, 50cm)**	○ **FOM: 0.110 (100mJ, 50cm)**	× FOM: 0.102 (75mJ, 50cm)
	PWR: 280 W WP: 0.8%	PWR: 467 W WP: 0.8%	PWR: 280 W WP: 1.0%	PWR: 280 W WP: 1.1%	PWR: 280 W WP: 0.8%

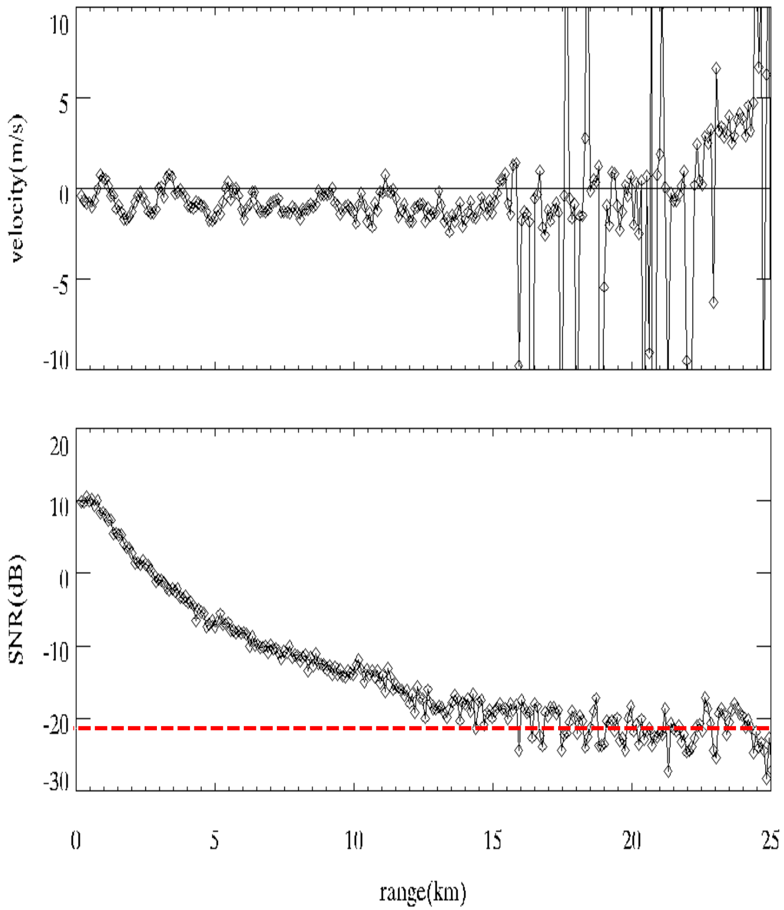
PWR: Power
WP: Wall plugin
Cf.
Requirements
FOM(Telescope diameter Φ40cm, PRF 30Hz): 0.125J×√30Hz×(0.4m)^2=0.110
FOM(Telescope diameter Φ50cm, PRF 30Hz): **0.080**J×√30Hz×(**0.5**m)^2=0.110
FOM(Telescope diameter Φ50cm, PRF 50Hz): **0.062**J×√**50**Hz×(**0.5**m)^2=0.110

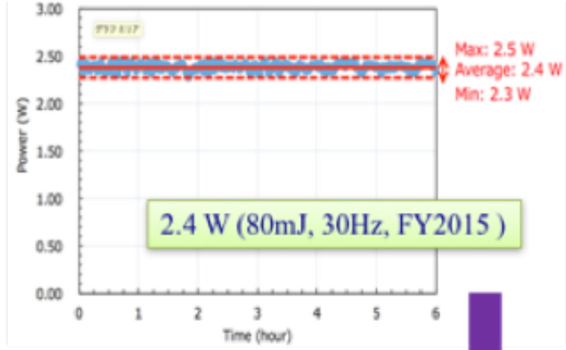
Recent activities at NICT

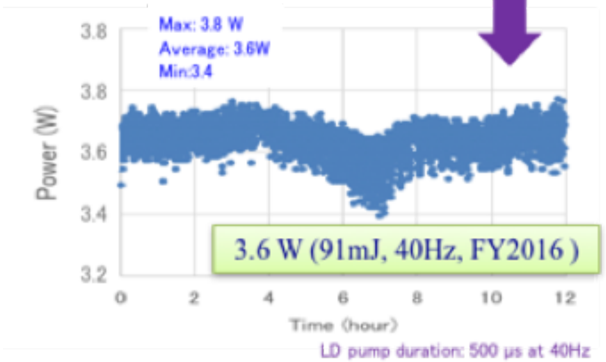
Ground-based 2-μm Doppler Wind lidar



20161014_151315062_ **1-sec wind measurement**







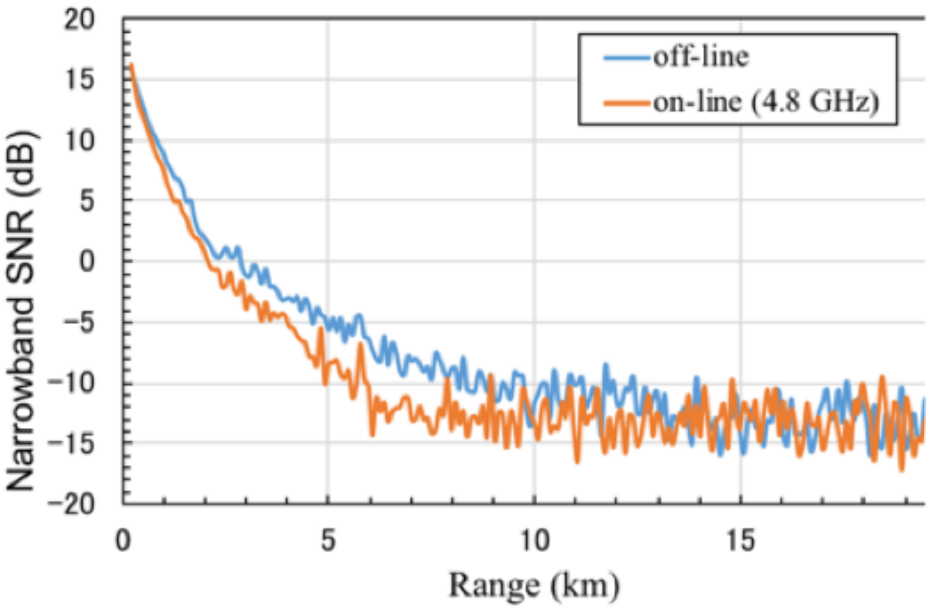
Shot noise = 9.2 dB

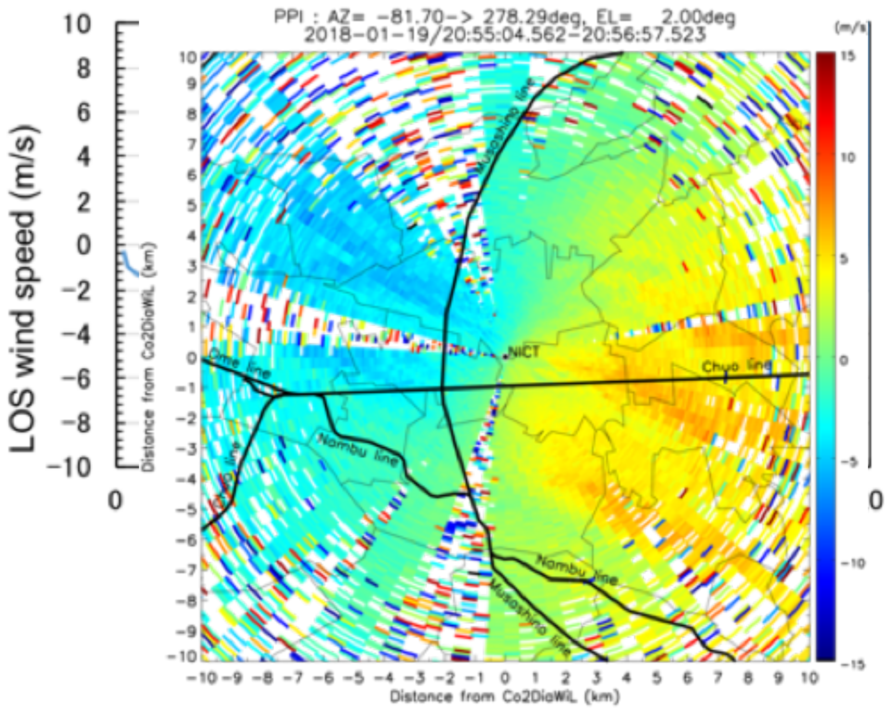
Optimization
- Pump duration, PRF
- Focal length of receiver
- Heterodyne detection

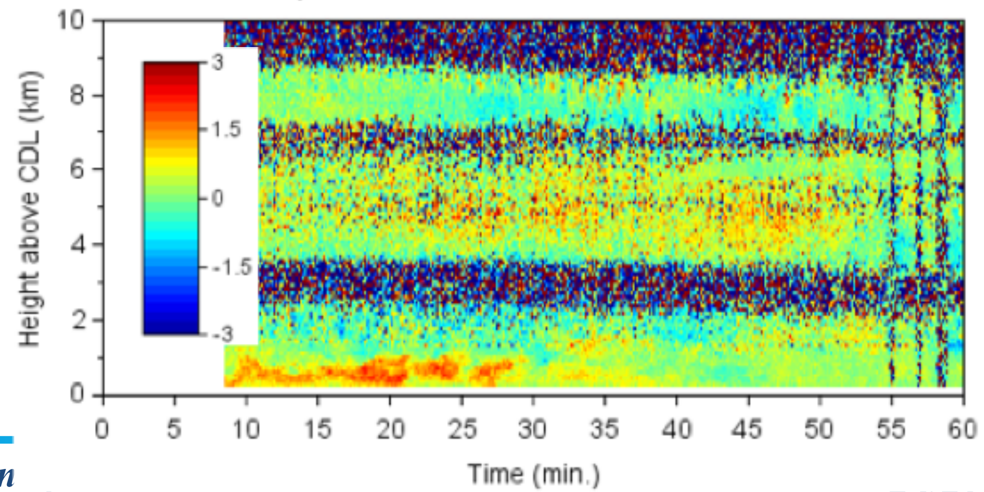
Hamamatsu C5658-4973

Airborne 2-μm coherent Lidar for wind and CO_2 measurement

Preliminary result of Airborne 2-μm coherent CO_2/Doppler Wind Lidar







Validation experiment for the Atmospheric Dynamic Mission-Aeolus

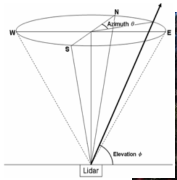
SHOKEN ISHII [*], HIRONORI IWAI [*], MAKOTO AOKI [*], PHILIPPE BARON [*], KOHEI MIZUTANI[*], SEIJI KAWAMURA[*], SATOSHI OCHIAI[*], ANDTOMOAKI NISHIZAWA [**]
[*] NATIONAL INSTITUTE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY
[**] NATIONAL INSTITUTE FOR ENVIRONMENTAL STUDIES

Preparation for Aeolus CAL/VAL

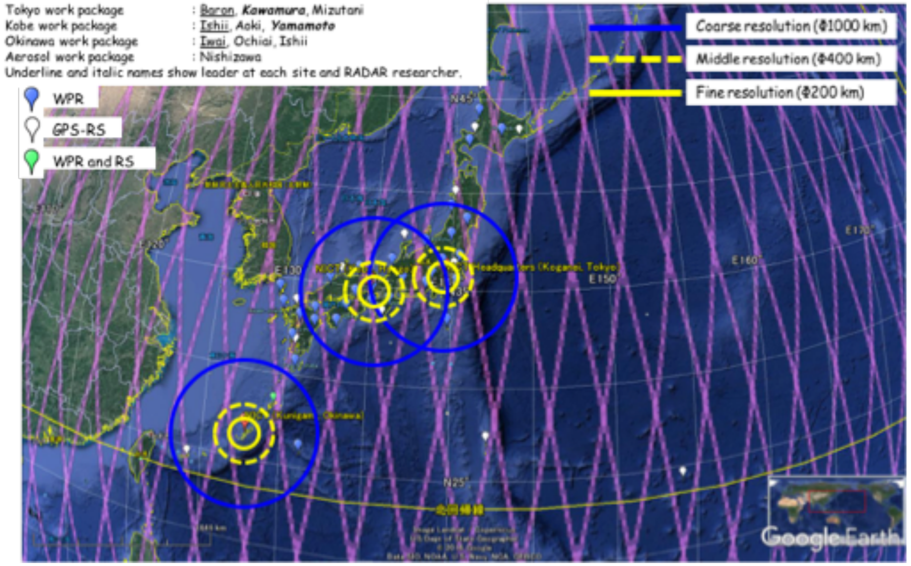
NICT Tokyo (35.7N, 139.5E)

- Two 2-μm coherent Doppler wind lidars
- 1.3 GHz wind profiler

VAD



CoIs: CO-Is / Baron, Kawamura, Mizutani



NICT Kobe (34.7N, 135.0E)

- 1.6-μm coherent Doppler wind lidar (WLS400S)

Head and controller for the scanner will be replaced in Kobe.

CoIs: CO-Is / Ishii, Aoki, Ochiai

NICT Okinawa (26.5N, 127.8E)

- 1.6-μm coherent Doppler wind lidar (WLS400S)
- GPS-sonde

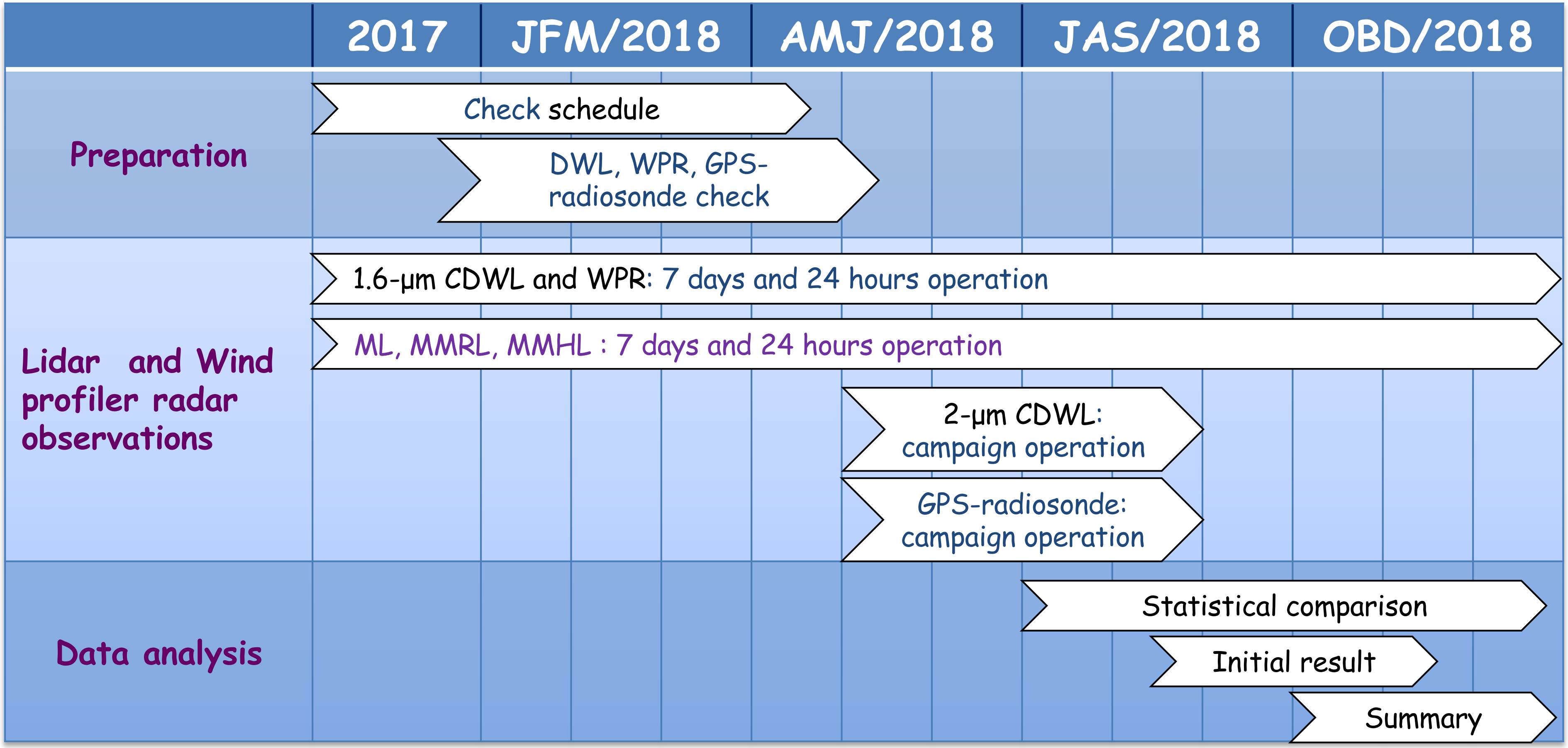
Send back to FR in November 2017.

AD, Power supply, EDFA, and circulator were replaced.

Shipped to JA around at the end of this February.

CoIs: CO-Is / Iwai, Yamamoto, Ishii

Schedule


2017
JFM/2018
AMJ/2018
JAS/2018
OBD/2018
Preparation
Check schedule
DWL, WPR, GPS-radiosonde check
Lidar and Wind profiler radar observations
1.6-µm CDWL and WPR: 7 days and 24 hours operation
ML, MMRL, MMHL : 7 days and 24 hours operation
2-µm CDWL: campaign operation
GPS-radiosonde: campaign operation
Data analysis
Statistical comparison
Initial result
Summary

Validation of the EarthCARE ATLID and MSI products using ground-based lidar and sunphotometry measurements in East Asia.

T. NISHIZAWA*[1], A. HIGURASHI*[1], R. KUDO*[2], H. IRIE*[3], K. YASUNAGA*[4], M. KATSUMATA*[5], K. YUMIMOTO*[6], S. ISHII*[7], H. OKAMOTO*[6], K. SATO*[6], S. KATAGIRI*[6], AND T. Y. NAKAJIMA*[8]

*[1]NATIONAL INSTITUTE FOR ENVIRONMENTAL STUDIES, JAPAN, *[2]METEOROLOGICAL RESEARCH INSTITUTE, JAPAN, *[3]CHIBA UNIVERSITY, JAPAN, *[4]UNIVERSITY OF TOYAMA, JAPAN, *[5]JAPAN AGENCY FOR MARINE-EARTH SCIENCE AND TECHNOLOGY, JAPAN, *[6]KYUSHU UNIVERSITY, JAPAN, *[7]NATIONAL INSTITUTE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY, JAPAN, *[8]TOKAI UNIVERSITY, JAPAN,

Validation of the EarthCARE ATLID and MSI products using ground-based lidar and sunphotometry measurements in East Asia.

Tomoaki Nishizawa[*1], Akiko Higurashi[*1], Rei Kudo[*2], Hitoshi Irie[*3], Kazuaki Yasunaga[*4], Masaki Katsumata[*5], Keiya Yumimoto[*6], Shoken Ishii[*7], Hajime Okamoto[*6], Kaori Sato[*6], Shuichiro Katagiri[*6], and Takashi Y. Nakajima[*8]

[*1]National Institute for Environmental Studies, Japan, [*2]Meteorological Research Institute, Japan, [*3]Chiba University, Japan, [*4]University of Toyama, Japan, [*5]Japan Agency for Marine-Earth Science and Technology, Japan, [*6]Kyushu University, Japan, [*7]National Institute of Information and Communications Technology, Japan, [*8]Tokai University, Japan,

1. Objectives

The objective of the proposed study is to validate the ATLID L1B, ATLID L2A, MSI L2A, and ATLID-MSI L2B products using ground-based lidar and sunphotometry data, and to contribute to the performance evaluation of EarthCARE observations.

- Main target parameters being Mie co-polar, Rayleigh, and cross-polar attenuated backscatter coefficients at 355 nm (ATLID L1B)
- 10 km-scale aerosol-oriented 355 nm extinction, backscatter, and depolarization profiles (A-AER/ATLID L2A)
- 355 nm cloud and aerosol extinction, backscatter, and depolarization profiles (A-EBD/ATLID L2A)
- aerosol layer products (A-ALD/ATLID L2A)
- aerosol optical thicknesses (AOTs) at 670 and 865 nm (M-AOT/MSI-L2A)
- columnar aerosol optical properties (AM-ACD/ATLID-MSI L2B).

Summary

Recent research and activities of 2-μm coherent Lidar at NICT are reported in the presentation:

- Development of a single-frequency 2-μm high pulse-energy laser meeting the requirements for the space-based CDWL
- Development of single-frequency semiconductor laser (on going)
- Q-switched output pulse energy of 125 mJ operating at 30 Hz at a laser rod temperature of -40C
- Preliminary results of airborne 2-μm coherent lidar
- Preparation for CAL/VAL activities for ESA missions: Aeolus and EarhCARE (on going)

Future works:

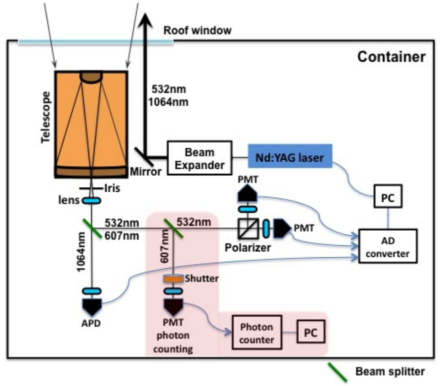
- Development of single-frequency semiconductor laser
- Demonstration of a single-frequency semiconductor laser with optical fiber amplifier
- Optimization of performance of a new 2-μm ring laser
- Environment test

Back up

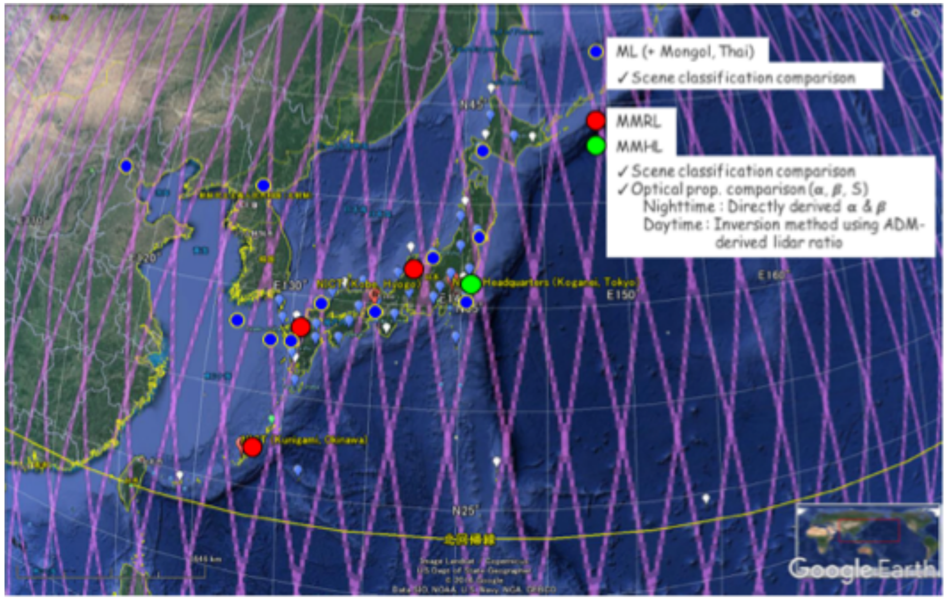
NIES aerosol profiling

●Dual-wavelength polarization Mie lidar (ML)

(2β(532,1064)+1δ(532))

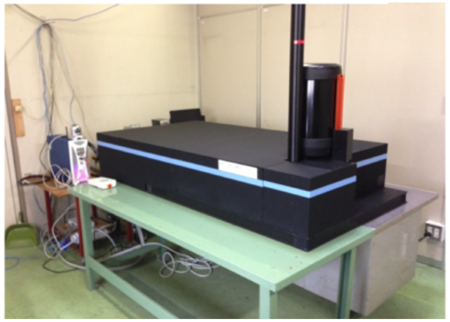


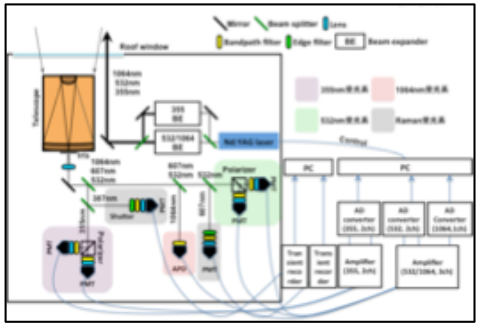
*24-hour continuous operation



●Multi-wavelength Mie-Raman lidar (MMRL)

(2α(355,532) + 3β(355,532,1064)+2δ(355,532))

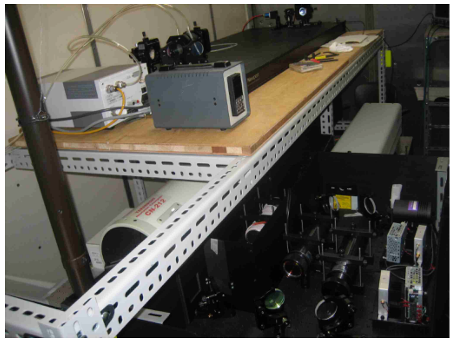


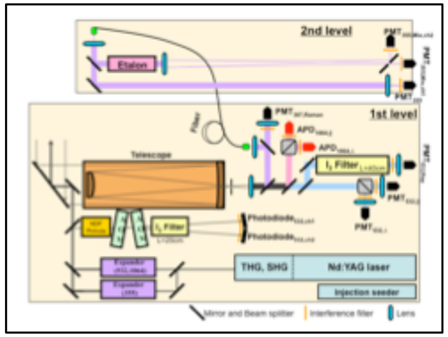


*24-hour continuous operation

●Multi-wavelength Mie-HSRL

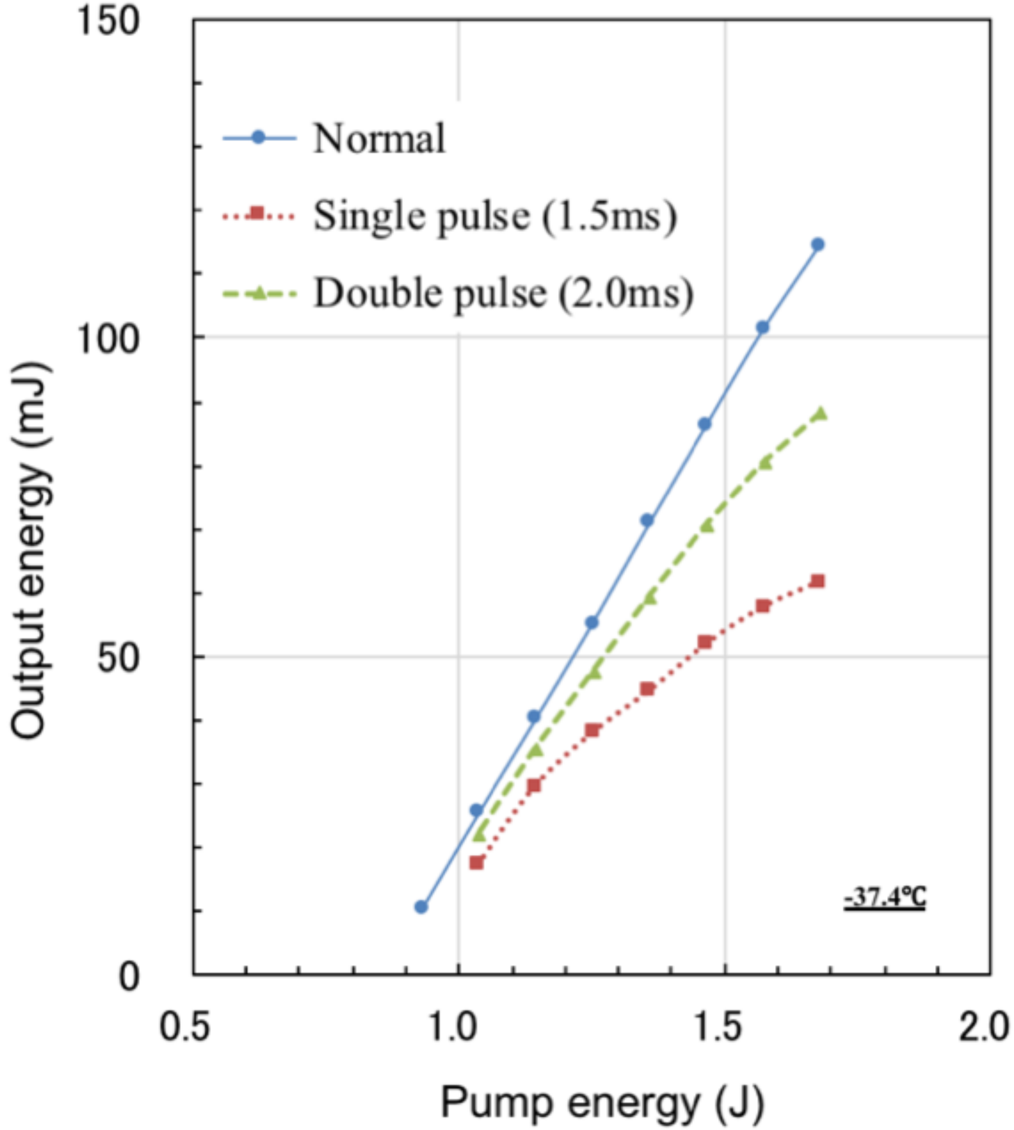
(2α(355,532) + 3β(355,532,1064)+2δ(355,532))





*24-hour continuous operation except for 355 HSRL

Lasing characteristics of 2-μm ring laser: double pulse



OSC
Laser rod: Φ4mm x 22 mm
Tm: 1.0 %, Ho: 0.7 %
AMP
Laser rod: Φ4mm x 33 mm
Tm: 1.0 %, Ho: 0.4 %

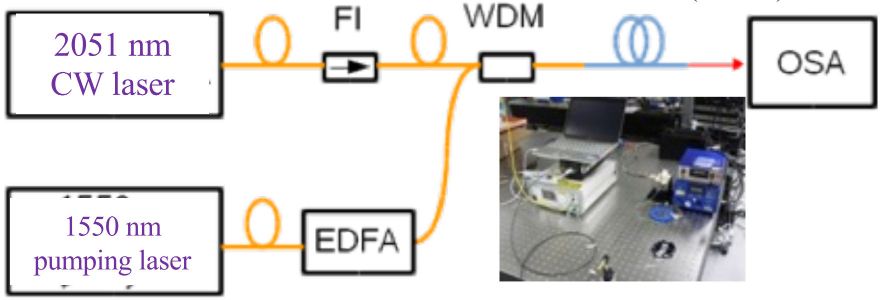
Tm-doped fiber amplifier for single-frequency 2-µm CW laser

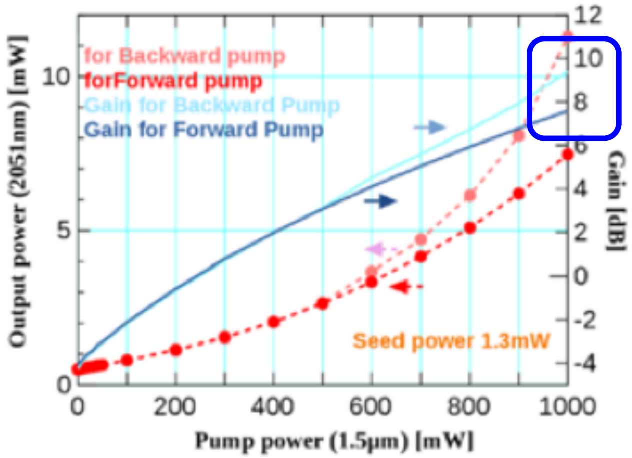
- Requirement for optical output power
  - Wavelength: 2051 nm
  - Gaing : 13 dB (input optical power:~1mW)
  - Output : 20 mW
- Other requirements
  - Long-term mechanical stability (vibration and shocks)
  - Maintenance-free
  - Compact and high efficiency (E-O conversion, removal heat)
  - Space-qualification

Erbium-Doped Fiber AMP:EDFA

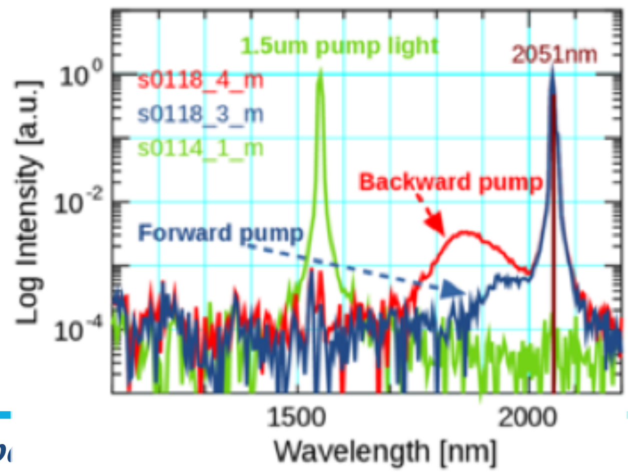
Thulium-Doped Fiber for space application
- Double-clad Tm optical fiber
- 793nm multi-mode LD pumping
- All optical fiber

Experimental setup of TDFA





Gain



Spectrum

2-µm laser technology required for space-based CDWL

Technology required for space-borne CDWL		Task
2-µm single-frequency Q-switched laser	Single-frequency 2-µm CW laser for seeding technique	●High power ●High stability ●Narrow line width ●Availability
	High pulse-energy laser	●High pulse energy ●High stability ● High efficiency
Detector		● High-speed response ● Low NEP

- Current Tm,Ho:YLF laser system: 80mJ × 30Hz.
- Laser rod temperature: -80 ºC
  - ➢ Power consumption of the cooling system

Target pulse energy: **125 mJ x 30 Hz**