Workshop on Space-based Measurements of 3-Dimensional Winds

(19-20 February 2025, NOAA Center for Weather and Climate Prediction, College Park, MD, US)

Current Status of Space-Based Doppler Wind Lidar Activity in Japan

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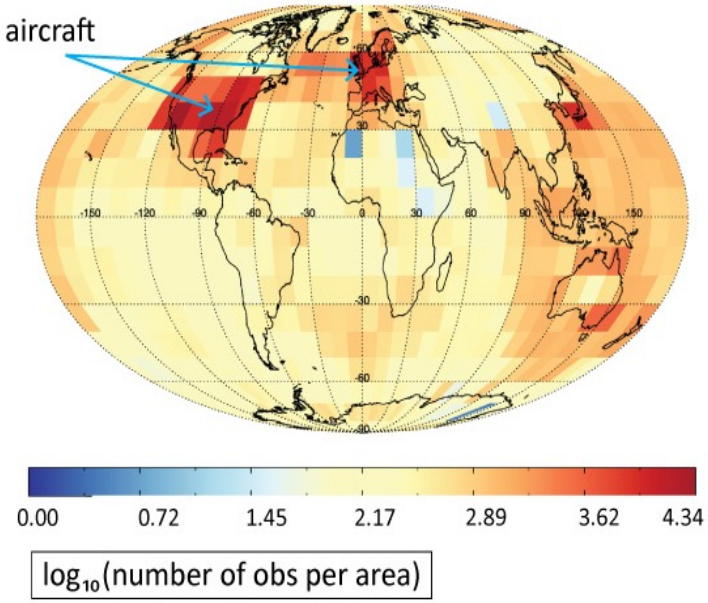
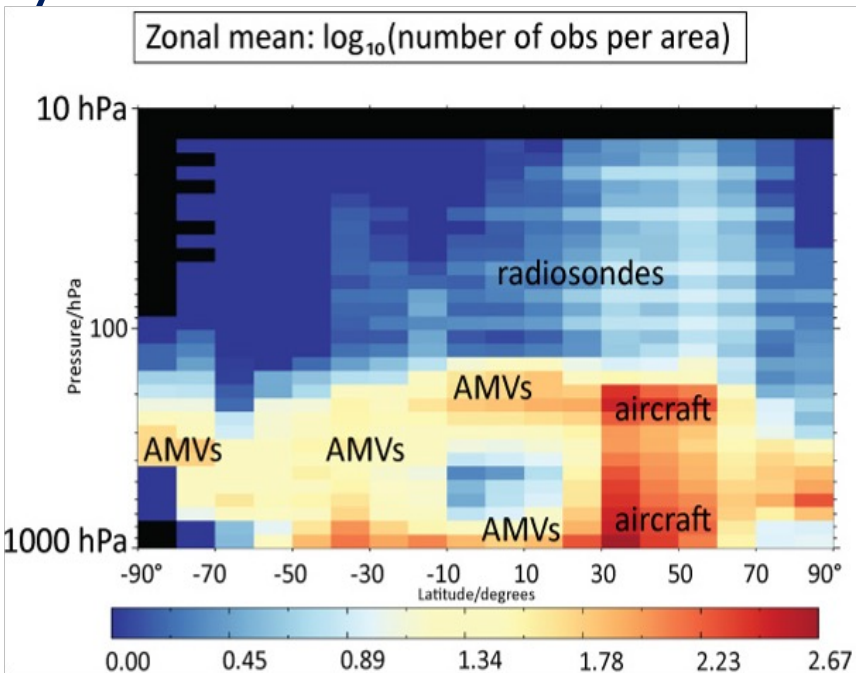
Outline

- Background
- Basic Plan on Space Policy
- Airborne 1.5-μm DWL
- Development of 2-μm laser
- Idea for 4D wind observation from space

Background

- Global 3D wind observation is important for weather prediction (NWP) and various meteorological studies.
- ESA launched the first space-based DWL, Aeolus, for global wind profile observations in August 2018. The Aeolus mission showed surpassing impacts on NWP and atmospheric science, and it demonstrated importance of global wind profiling.
- The Aeolus mission ended operations on 30 April 2023 and reentered on 28 July 2023.





- Uneven distribution
- Upper troposphere and stratosphere still poorly sampled

Rennie and Isaksen (2018)
https://www.ecmwf.int/sites/default/files/aeolus-blog-image2-wind.jpg

Atmospheric Motion Vector

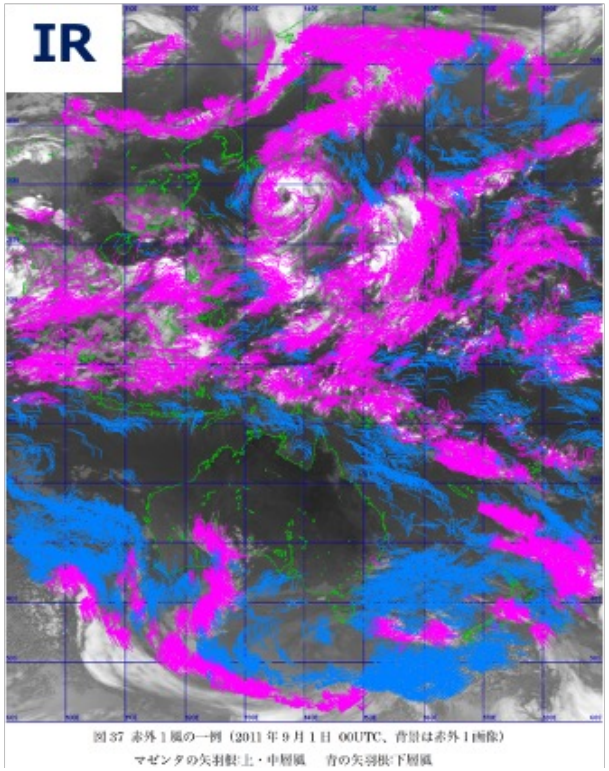


図 37 赤外 1 風の一例（2011 年 9 月 1 日 00UTC、背景は赤外 1 画像）
マゼンタの矢羽根:上・中層風　青の矢羽根:下層風

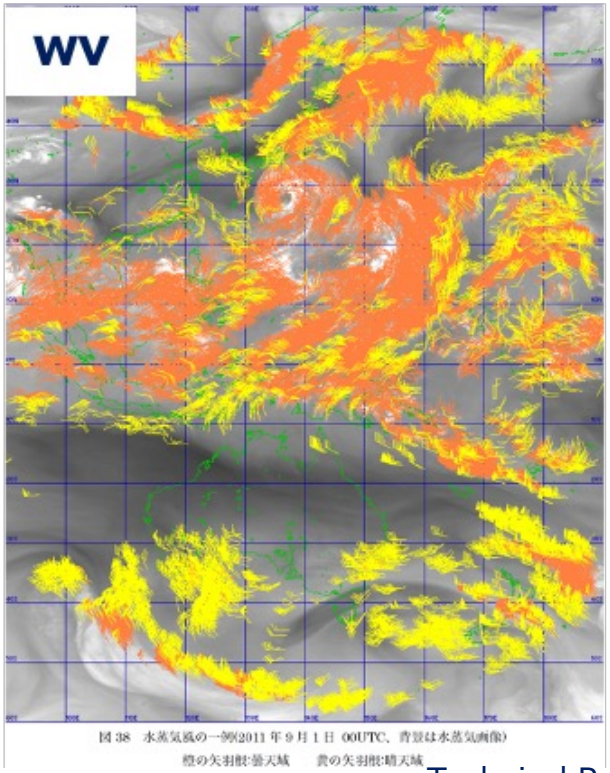


図 38 水蒸気風の一例(2011 年 9 月 1 日 00UTC、背景は水蒸気画像)
橙の矢羽根:晴天域　黄の矢羽根:晴天域

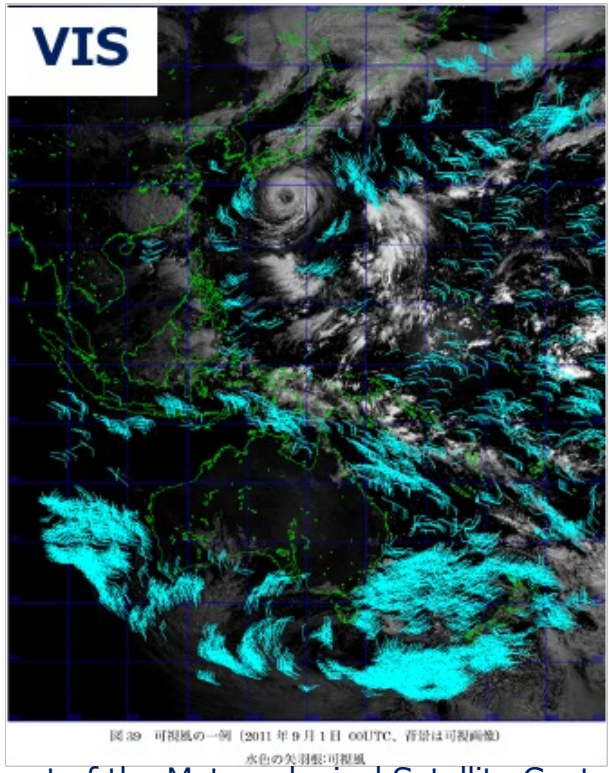


図 39 可視風の一例（2011 年 9 月 1 日 00UTC、背景は可視画像）
水色の矢羽根:可視風

Technical Report of the Meteorological Satellite Center, No. 58

Height assignment of the AMV remains very inaccurate, and it causes significant vector wind errors

30–60 hPa differences in the height assignment between the AMV and other instruments

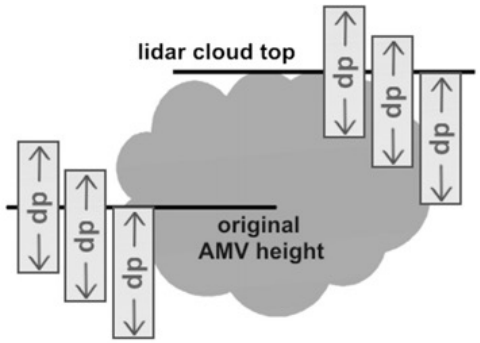
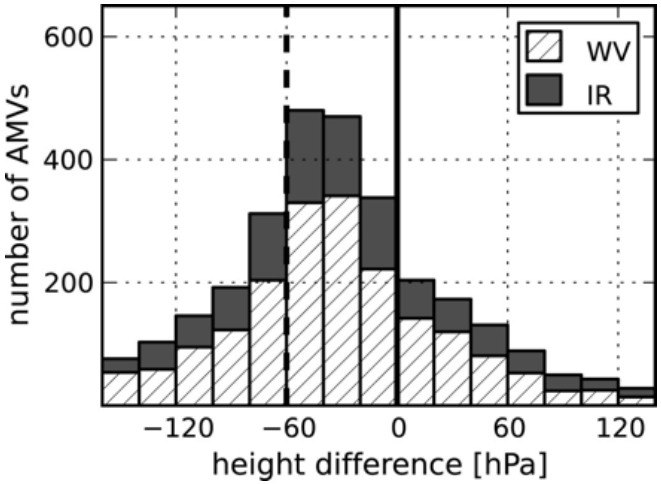


FIG. 3. Schematic illustration of the height-correction method, using three layer positions (centered, 25%/75% above/below, and below) relative to the original AMV height and relative to the lidar cloud-top height for layers of varying depth *dp* ranging from 0 to 200 hPa.



(Velden and Bedka 2009; Folger and Weissmann 2014)

3D wind observation with DWL and AMV

Aeolus L2b wind product (Mie-channel) is useful wind data as a comparison standard to characterize AMV wind.

(Lukens et al., 2022)

- AMV
  - Cloud and Water vapor features
    - 10-15 mins, full disk observation, full disk
- Coherent DWL
  - Wind measurement sensitive to cloud and aerosol
  - Accurate doppler shift measurement, low-bias

We can expect that coherent DWL and Aeolus-2 Mie channel wind measurements improve height assignment and measurement issue of AMV.

Basic Plan on Space Policy

- Next geostationary meteorological satellite Himawari 10 carrying a hyper-infrared sounder will be launch in FY2028. There are limits to the altitude estimation by passive sensor observations, a satellite sensor capable of observation with high precision and high vertical resolution is required.

- The Cabinet Office of Japan revised the Basic Plan on Space Policy in June 2023. In the chapter 2 Goals and Future vision of the plan, the basic plan states that Doppler Wind Lidar for three-dimensional (3D) global wind profiling as well as space-based laser altimeter for 3D mapping is expected as one of future space-based lidar techniques.

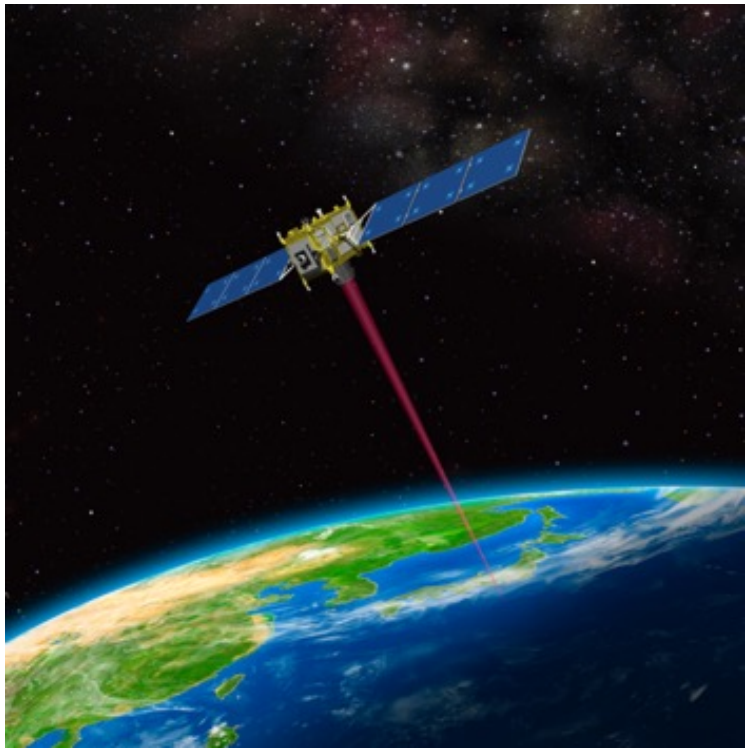
Japanese working group is continuing its research on the feasibility of the space-based coherent Doppler Wind Lidar (CDWL) from the technical and scientific viewpoints.

Concept of future space-based CDWL

	Space-based CDWL
Orbital altitude / Orbit	<300 km / Polar
Transmitter	Plan 1 : 1.5-μm, 7.5 W Plan 2 : 2-μm, 5.4 W
Receiver	0.6 m / 1 look
Target horizontal resolution	≤100 km
Horizontal measurement resolution	≤3 km
Target vertical resolution	Altitude 0-2 km: <0.5 km Altitude 2-12 km: <1 km
Nadir angle	35 degree
Looking angle	90 degree
HLOS dynamic range	-100 ~ 100 m/sec
Timeliness	3 hour
Detectability	95 %

Requirement of HLOS wind measurement

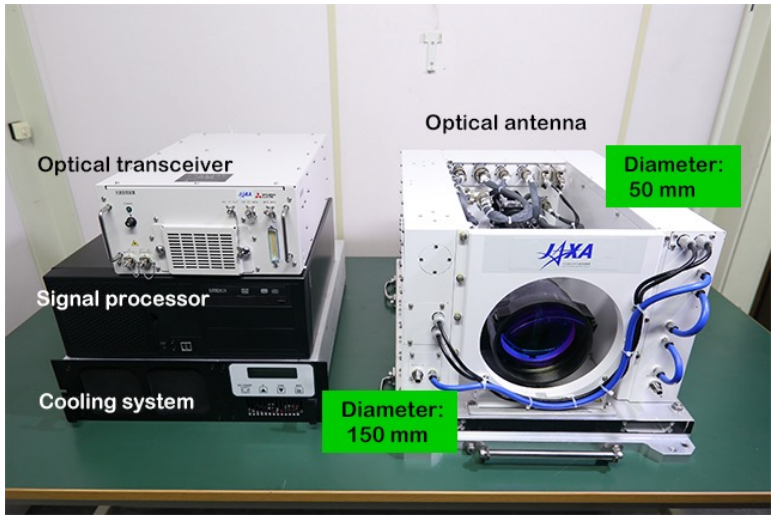
Altitude (km)	Vertical resolution (km)	HLOS wind speed error (m/s)
0-2	0.5	≤1
2-12	1	≤2



A candidate launch vehicle is “Epsilon rocket” developed by JAXA.

Reactivation for future space-based DWL development

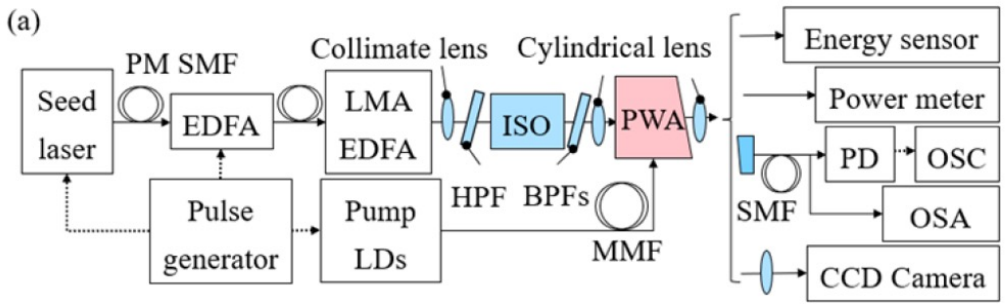
- Airborne Coherent Doppler Wind Lidar
  - Promoting data application research using CDWL
  - Airborne demonstration experiments for data processing and validation, and evaluation by users
  - Feedback to technical and scientific requirements for future space-based CDWL



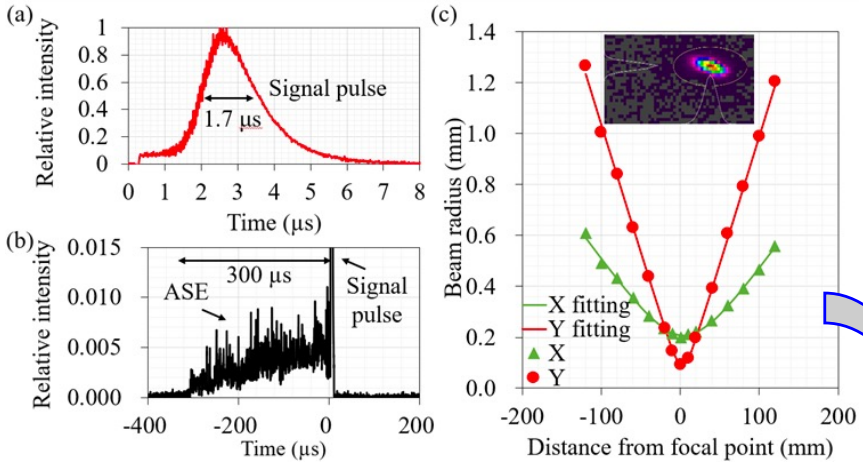
https://www.aero.jaxa.jp/eng/research/star/safeavio/

  - Overhaul of airborne CDWL (ex. SafeAVIO projects)
  - JAXA asks the manufacturer to diagnose parts required for the repair for the airborne DWL in the second half of 2024. (2024)
- Research and Development of 1.57-μm laser
  - Research and development of 1.57-μm laser is suspended until the situation changes.
  - Continue to exchange information, including manufactures.
  - TIT and TMU are conducting development of a next-generation 2-μm laser.

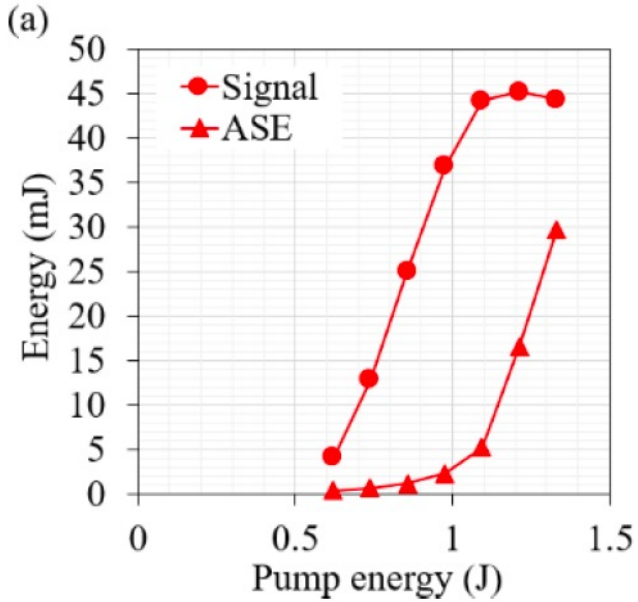
Development of key technology: 1.5-μm laser



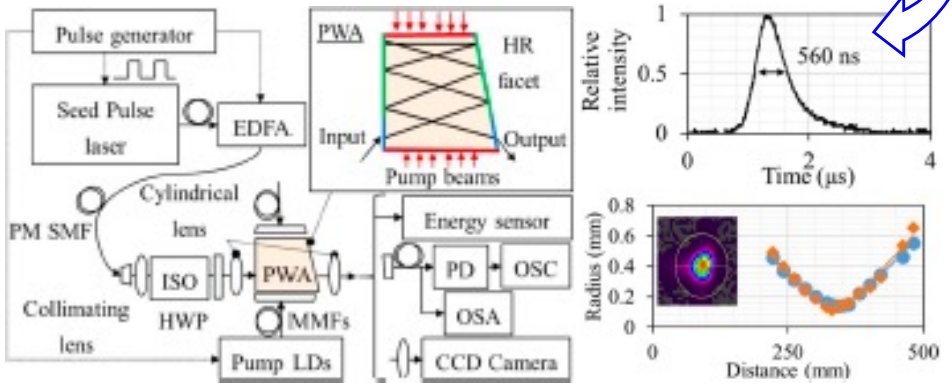
Schematic diagram of the experimental setup for 1.5-μm laser



Measured pulse shape of the output beam from the PWA, (b) Enlarged view of the base of the output pulse shape, and (c) Measured beam quality.



Measured output pulse energy from the PWA.



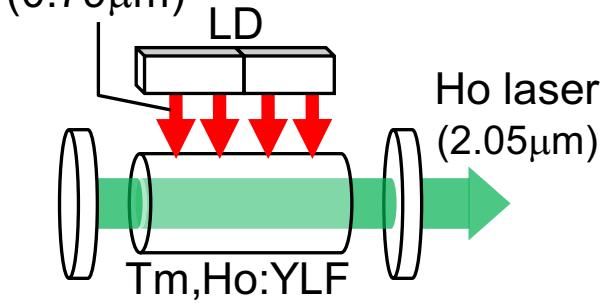
Nomura et al. (2024) https://doi.org/10.35848/1882-0786/ad3a2e

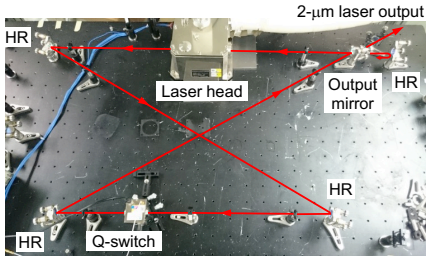
Concept of intracavity-pumped Ho:YLF lasers

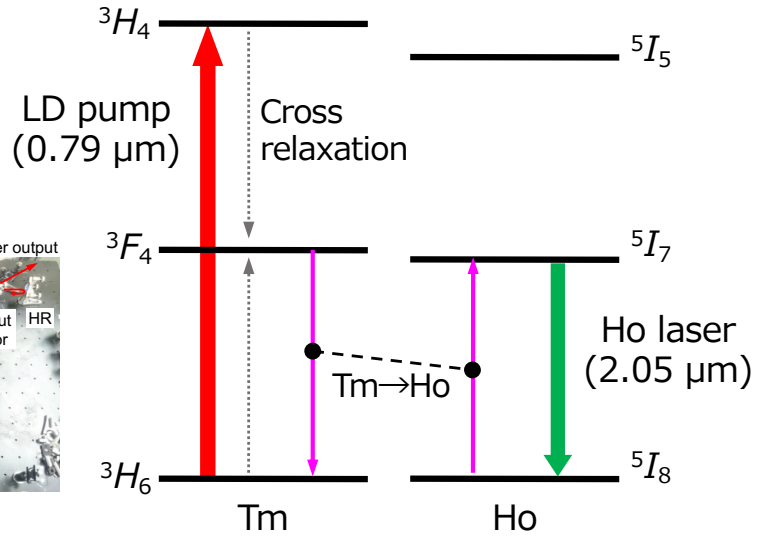
Side pumping laser

Power consumption is high.

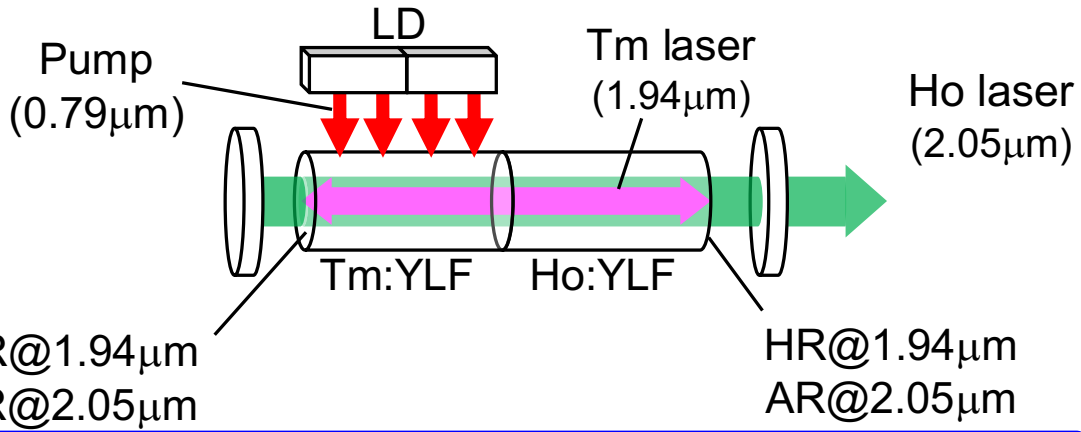
This type laser need to cooled down crystal to very low temperature.

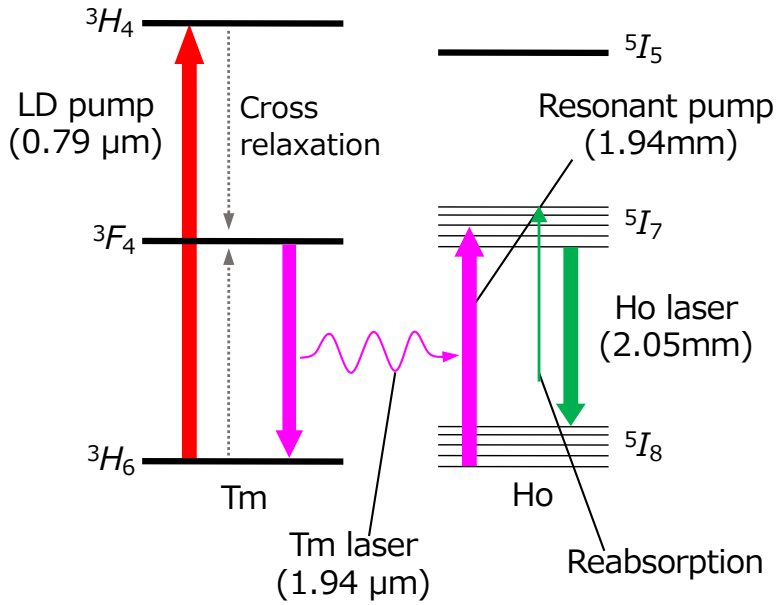






Intracavity resonant pumping type laser

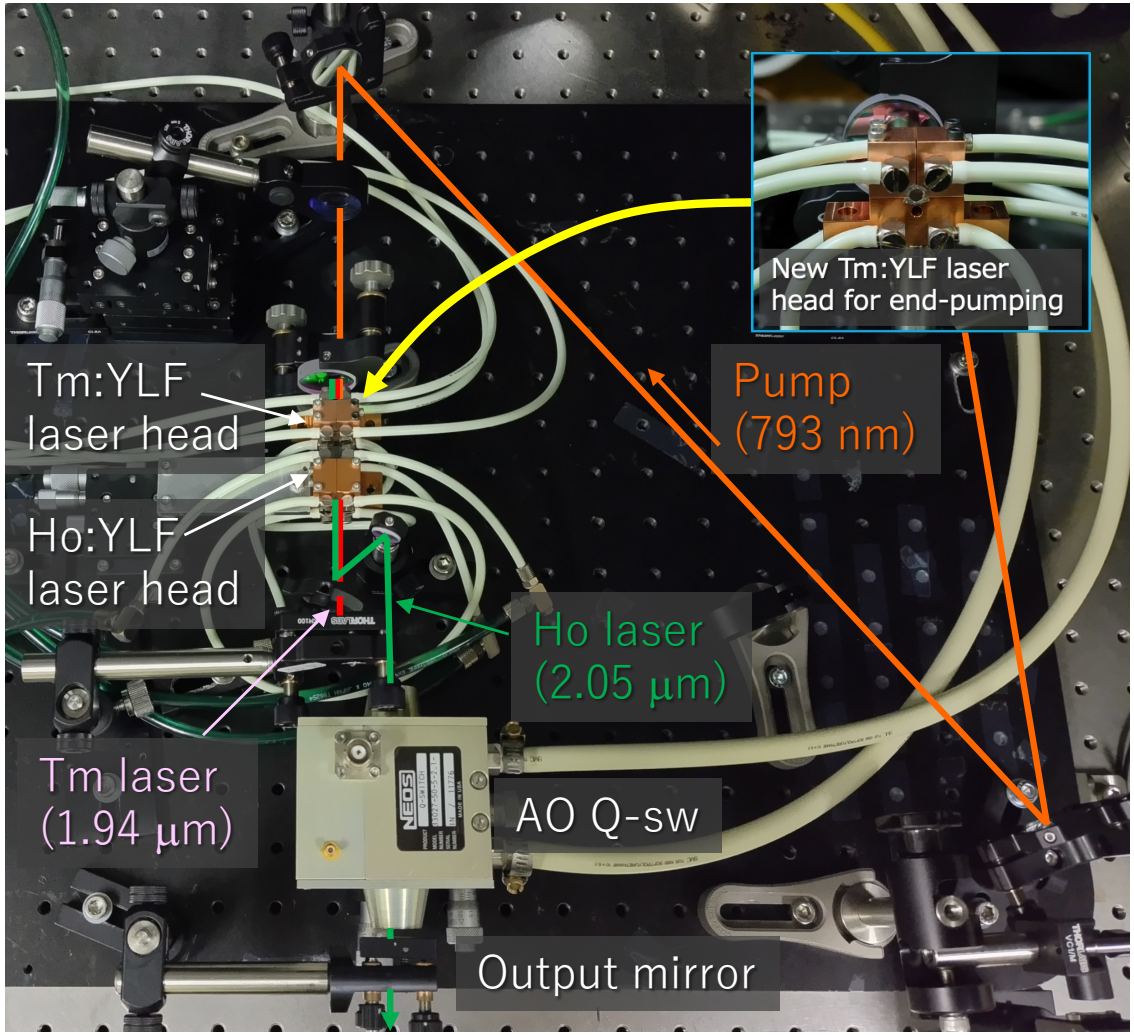




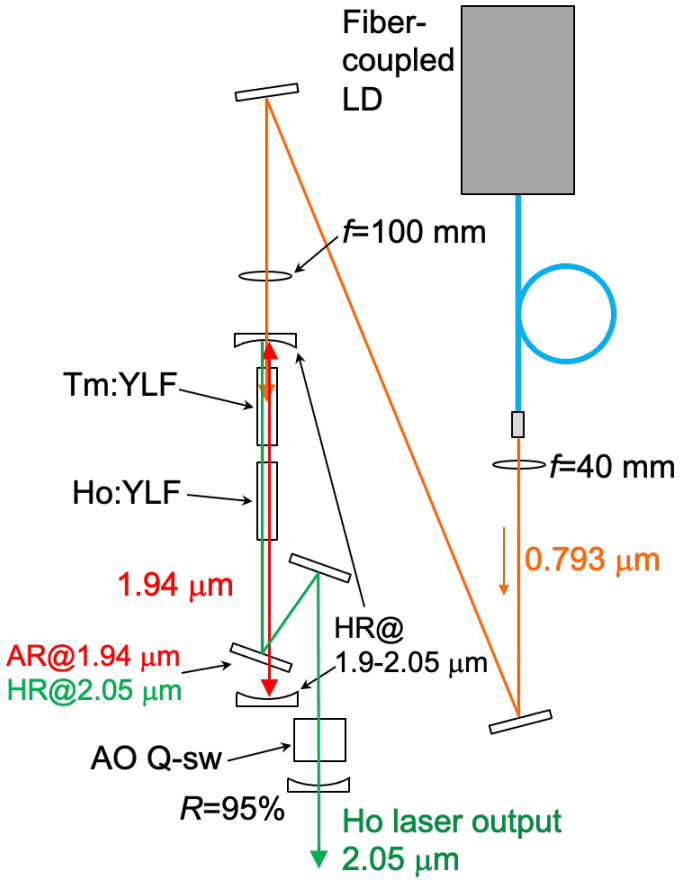
Efficient absorption of the Ho laser light can be achieved even **at room temperature** due to the intracavity multi-pass absorption if the short Ho crystal is used.

Sato (2024)

Development of a Q-switched laser using a new end-pumped Tm laser head

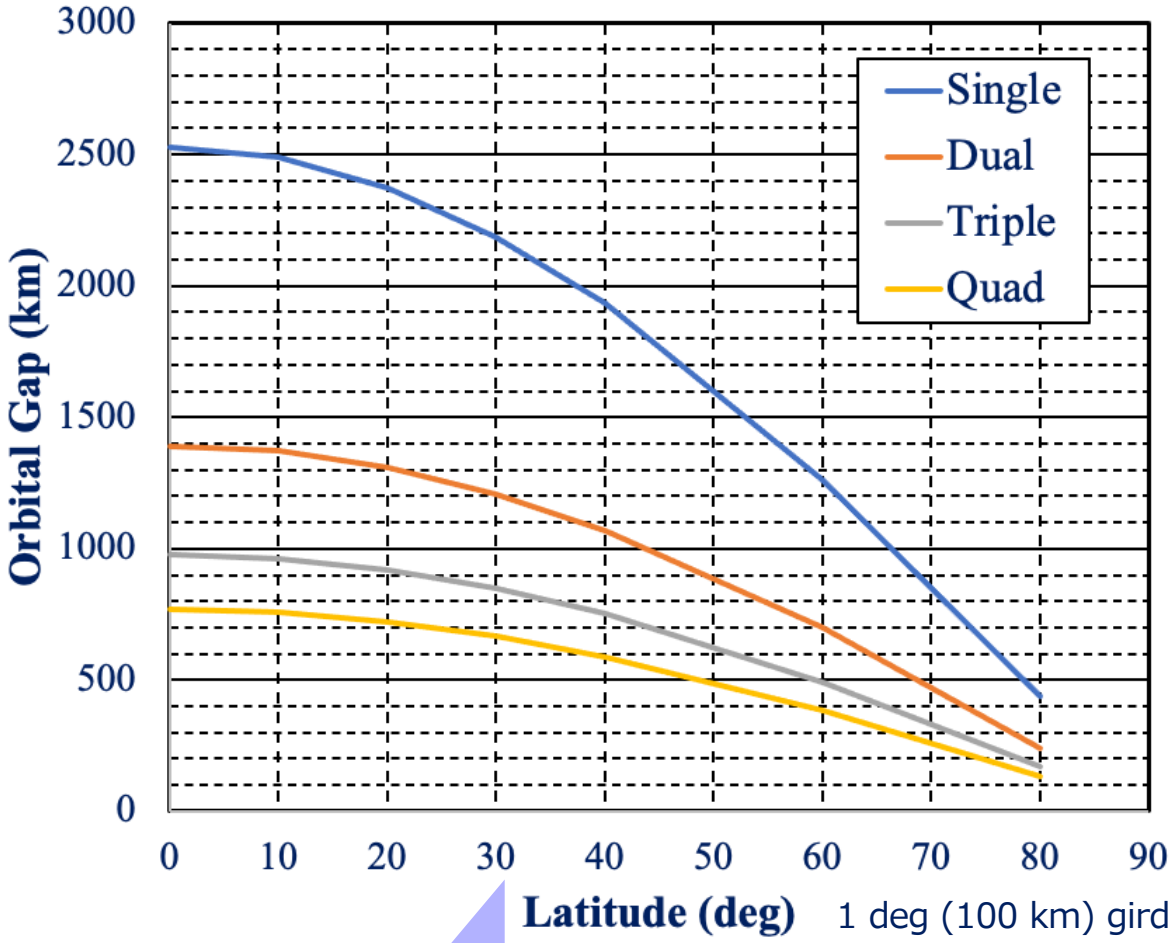


Tm crystal	
Material	6%Tm:YLF
Size	ϕ3 mm×8 mm



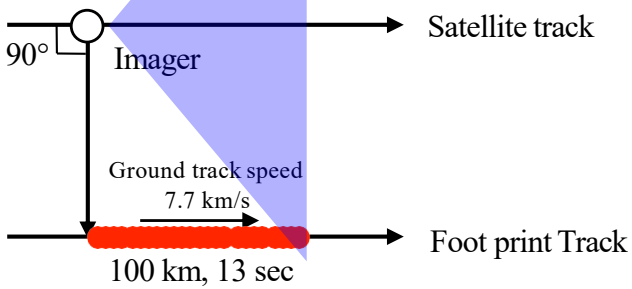
- Ho laser output energies higher than 10 mJ were obtained in the normal-mode operation.
- The laser experiment in the Q-switched mode will be performed in future work.

JAXA DWL observation with Aeolus-2 / with Aeolus-2 plus

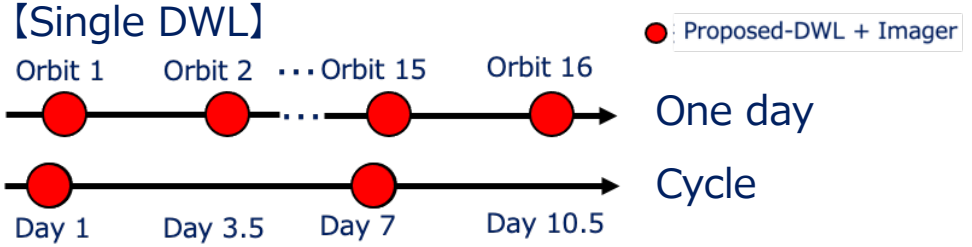


1 deg (100 km) gird

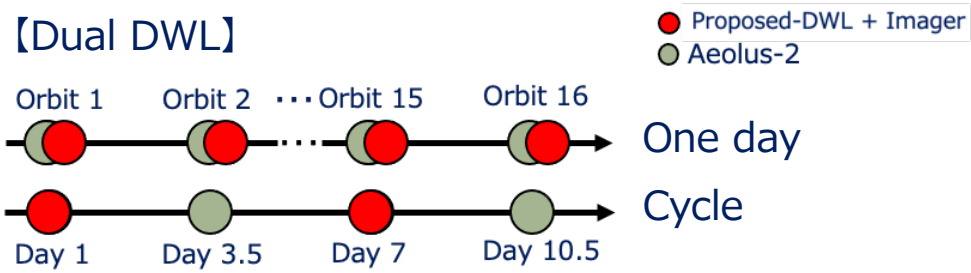
JAXA DWL + Imager, Aeolus 2, US-DWL



【Single DWL】

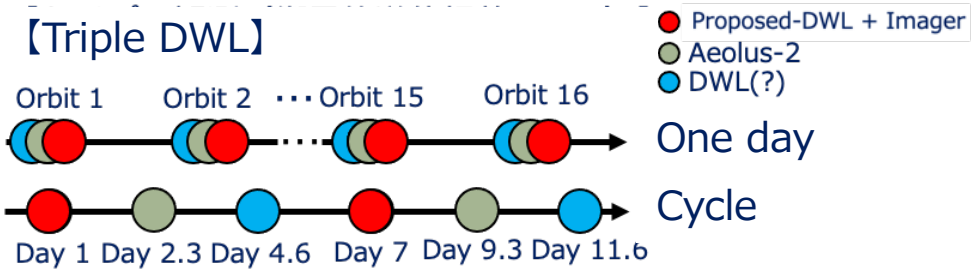


【Dual DWL】



Phase difference: 180 degree
Time difference: 12 hours

【Triple DWL】



Phase difference: 120 degree
Time difference: 8 hours

4 DWLs are better than 3 DWLs from perspective of the constellation…(🤔).

Summary

Japanese Cabinet office (CAO) revised the Basic Plan on Space Policy on 13 June 2023. The basic plan states that Doppler Wind Lidar for three-dimensional (3D) global wind profiling is one of future space-based lidar technique. JAXA, TMU, JMA/MRI, and our colleagues continue to conduct feasibility studies on the future space-based CDWL.

- We are studying 4D global wind observation scenarios using JAXA DWL, Aeolus-2, AMV, and other space-based DWLs, as well as cloud and aerosol spin-off products. Although studies for space-based DWL was temporally suspended due to difficult situation in 2022, JAXA reconstructed core member of DWL WG and reactivated activities for the space-based DWL.
- JAXA considers overhaul of an airborne CDWL and demonstration experiment for wind profiling using the airborne CDWL. They asked the manufacturer to diagnose parts required for the repair for the airborne DWL in the second half of 2024. (2024)
- A new intracavity-pumped 2-μm laser was successfully demonstrated by using the end-pumped Tm:YLF laser as a pump source. A normal-mode output energy of over 10 mJ was achieved in the 2-μm laser. The experiments of the intracavity-pumped Ho:YLF laser in the Q-switched mode are on-going.

Acknowledgments

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