MDS-lidar scientific mission

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Introduction

The global warming issues have been widely discussed among not only scientists but also policy-makers because of their seriousness to the human society. The lidar communities in the world have also been seeking for what they could do to contribute to solving those issues by applying lidar techniques that they have long been engaged in to develop. Space-borne lidars is one of their answers to this question.

Space-borne lidars especially for measuring distributions of clouds and aerosols are one of the most feasible and potential lidar instruments which could be applied to the problems of global warming. This is because clouds are one of the most important factors affecting global climate through radiation balance between atmosphere and earth surface and because feedback mechanisms between global warming and clouds are still not well understood. Lidar technologies for measuring clouds are matured quite well at least for ground-based and aircraft measurements. It is quite natural to consider the possibility of lidars onboard satellite for global observations of clouds, especially when considering that clouds are one of the most difficult targets to investigate in terms of their global distribution and its variability.

In 1994, NASA conducted an experiment of lidar onboard a space shuttle (LITE: Lidar In-space Technology Experiment) and showed its capabilities to detect clouds and aerosols from space although the experiment period was only 53 hours. A next step would be a satellite-borne lidar for a long term monitoring of the atmosphere. A few years ago, we conducted a four-year study regarding feasibility of space-borne lidars for application to global environmental issues. We reached a conclusion that the most feasible and effective candidate for lidars to be developed would be a type of Mie lidar for measuring three dimensional distributions of clouds and aerosols. NASDA started their studies on satellite-borne lidars and now is about to embark on the MDS-lidar project, which is described in detail in separate papers. A scientist group has also been established in Japan to promote this NASDA's attempt from data users' side.

This paper discusses some important study topics regarding cloud/aerosol observations by the MDS-lidar and possible study topics using MDS-lidar data. Some of the contents were discussed at the MDS-lidar team meetings this year.

Scientific missions of MDS-lidar

Climatologies of clouds/aerosols in the tropical and subtropical regions have been considered most important from the viewpoints of MDS-lidar measurements. They includes:

(1) high altitude clouds (cirrus) climatology,

(2) multiply-layered clouds climatology, and

(3) stratospheric and tropospheric aerosols studies.

For the cloud studies, climatological analysis of layer top/bottom height distribution, fractional coverage, and optical depth must be carried out. Diurnal variation of these parameters are also important because radiation budgets varies in different sun elevation conditions.

Stratospheric and tropospheric aerosols are another important targets because aerosols affects radiation balance directly and indirectly. So their optical properties as well as geographical distributions and variability must be known. It would be also possible to treat the aerosols as tracers for atmospheric transport processes. Targets are volcanic aerosol, desert aerosols such as Saharan and Asian, and marine boundary layer aerosols.

Case studies of radiation field analysis should be very informative in terms of relationship between clouds and radiation field. This kind of study requires other existing passive sensors data that are simultaneously obtained with the lidar measurements. This should be used as the basis for future full-scale space-borne lidar missions

MDS-lidar measurement characteristics

The main targets of the MDS lidar are clouds in daytime and nighttime and aerosols in nighttime from the surface to 35 km in the atmosphere according to the NASDA's plan. Spatial resolution are designed as 1.5 km horizontally and 100m vertically for clouds measurements by analog detection mode, and 150 km horizontally and 1 km vertically for aerosols measurements by photon counting detection mode. Geographical coverage is limited to the tropical and subtropical regions (30 S to 30 N) because of the planned satellite inclination angle of 30 degree. The satellite will have a non-sunsynchronous orbit, which makes observations of diurnal changes possible.

Data rate will be about 85 kbps at the maximum when taking data at 450 levels from -5 km to 40 km in altitude both for one analog channel (12 bits) and two photon-counting channels (12 bit x 2) at every 1.5 km along track, including some housekeeping data of 4 kbps. For the photon-counting channels, data taken with this mode will be appropriately averaged to give spatial resolutions specified above.

Onboard recorder capacity, which will be determined soon, has to be large enough to effectively use the downlink capability to the maximum extent and to provide global observation opportunities. Data downlink capability is expected to be 1 Mbps when using S-band transmission and the data amount transmittable per day will be about 1.1 Gbits per day, when assuming that only a single Japanese station will be assigned for this purpose. This gives the minimum possible measurements duration as 3.5 hours per day. If data amount reduction is possible, the duration gets longer. For that to happen, it would be recommended that the MDS-lidar have on-board capabilities of changing accumulation number (horizontal resolution), measurement range, and vertical resolution according to measurement purposes and targets, which is a problem of observation strategy to make scientifically valid observation plans.

Synergism

It would be necessary to utilize lidar data which has been taken in accordance with other passive sensors measurements in order to make quantitative analysis of optical properties. Data that could be used are those imagery data and vertically sounding data obtained by geostationary meteorological satellites and polar-orbiting meteorological satellites. Detailed studies are to be done regarding feasibility of synergistic use of other sensors data. This will also be a basis for future mission designs.

Researchers team for promoting NASDA's project

The researchers team for the MDS-lidar project is aiming at conducting;

1) scientific investigations on mission requirements,

2) data processing algorithms studies,

3) establishment of an observation strategy for effective data acquisition (sampling problem), and

4) improvement of climate prediction models by use of lidar data. More specifically, the following researches are now planned for MDS lidar experiments; that is, as preparatory studies, algorithms for data processing to derive quantitative information from measurement data, and strategy for effective data acquisition to get comprehensive data set under various limitations of satellite operation. Furthermore, data use study will be conducted regarding process studies of radiation/cloud/aerosol interaction, cloud/aerosol climatology, and climate modeling with use of cloud/aerosol information.

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Purpose of presentation:

To discuss possible study topics regarding cloud/aerosol observations by MDS-lidar

Outline of presentation

Background
Scientific targets of MDS lidar
Coverage consideration
Multiple scattering effects
Synergism with passive sensors
Investigations planned by MDS-lidar team

GKSS

2. Which information should be provided by observational systems on aerosol and cloud layers within a grid cell ?

(1) Radiative transfer properties of a field (within a grid area)

- (a) fractional coverage
- (b) vertical extent (3-d) / multiple layers
- (c) altitudinal range
- (d) particle concentrations/total volume contents --> IWC/LWC
- (e) particle size distributions
- (f) particle shapes
- (g) horizontal structures of these quantities (b) through (f)
- (h) particle phase (snow/ice) - a shape factor ?

(2) Time variability of all quantities mentioned above

- (a) amount
- (b) density
- (c) particle / drop size distributions

Nara 1995

by Raschke (1995)

GKSS

4. Requirements for active probing - project proposals

More accurate knowledge is required on

1	• cloud boundary altitudes (± 200 m —> ± 1.2 K)	CPR, L
4	• cloud top morphology	CPR, L
2	• multiple cloud layers (thin on top of others)	CPR, L
3	• internal structure, LWC and IWC	CPR
1	• aerosol (and pre-condensation phase) layers between cloud field elements	L
2	• aerosol layers on top the planetary boundary layer	L
3	• low level fog	L

CPR = cloud profiling radar (~3 to 8 mm)

L = lidar

Nara 1995

by Raschke (1995)

Scientific background:

(1) Global warming and clouds/aerosols

(2) Water/energy circulation and clouds

(3) Transport in the upper atmosphere

MDS-lidar characteristics (tentative)

Main target:
daytime and mighttime clouds and night time aerosols

Spatial resolution/coverage
1.5 km horizontal, 100m vertical for analog detection
150 km horizontal, 1 km vertical for photon counting detection
tropical and subtropical regions (30 S to 30 N)
non-sunsynchronous orbit

Detection:
Analog (AN) for Fundamental wavelength
Photon counting (PC) for Fundamental and Second Harmonics

Scientific missions of MDS-lidar

Climatologies of clouds/aerosols in the tropical and subtropical regions

(1) High altitude clouds (cirrus) climatology

(2) Multiply-layered clouds climatology

cloud layers top/bottom
cloud fractional coverage
cloud optical depth
diurnal variation

Scientific missions of MDS-lidar (cont'd)

(3) Stratospheric and tropospheric aerosols

aerosol optical depth
aerosol layer height/thickness
diurnal variatrion (troposphere)
transport
desert aerosols(Saharan, Asian dusts)
volcanic aerosols

Case studies of radiation field analysis
using lidar data as well as other passive sensors data, which will also be the basis for future full-scale space-borne lidar missions

Data acquisition capability

Mission life: 1 year

Data rate:
Mission data 81 kbps
- 450 levels from -5 km to 40 km for AN and PC
- 5 Hz (every 1.5 km along track)
- 12 bit for AN
- 12 bit x 2 for PC

Housekeeping data 4 kbps
Total
- 85 kbps for AN + 2 PC
- 35 kbps for AN only
- 62 kbps for 2 PC

Data acquisition capability(cont'd)

Onboard recorder

Detailed specification (TBD)

Previous examples
e.g. 2 x 450 Mbits recorders for OICETS
900 Mbits / 85 kbps = 10600 sec (= 180 min. = 3 hours)

Data downlink capability

Station: Katsuura station, Japan
Visibility: 18 minutes for downlink to Katsuura per day

S-band transmission: 1 Mbps speed (12 times data rate)

Transmittable data amount per day:
1 Mbps x 18 min./day = 1080 Mbits/day (= 3.5 hours/day in full data taking)

Maximum data amount for one revolution:
85 kbps (for AN + 2 PC) x 100 min. = 510 Mbits

Conclusion regarding coverage

Data acquisition possible to full extent for 2 revolutions out of 14 a day

1 week continuous measurements required for full but rough global coverage

----> Almost satisfactory, but

Coverage expandable by reducing data rate, or by optimizing sampling plan

Recommendations for MDS-lidar would be:
to have capabilities of
selestion of accumulation number (horizontal resolution),
selection of measuement range, and
selection vertical resolution

Multiple Scattering Summary

- water clouds:
  - in dense clouds scattered light is trapped within LITE FOV
  - high-order scattering produces very significant pulse stretching
  - multiple scattering prevents optical depth retrieval using single-scatter approaches (eg: Klett)

- cirrus:
  - multiple scattering effectively reduces cloud extinction by factors which can be significantly > 2
  - reduced attenuation allows penetration of nearly all cirrus

- downlooking geometry + enhanced penetration results in better climatology of cloud height than from surface

Winker and McCormick (1995)

Multiple scattering

Clearly seen in LITE data

Gives better detection of cloud base even through clouds

Complicates quantitative analysis for optical characteristics

Multiple IFOVs detection recommended for future missions

Synergism

Geostationary meteological satellite
Polar-orbiting meteological satellite

Quantitative analysis possible
Global coverage (interpolation)

Statistical analysis required in any case because of difficulty in identifying the exact measurement points

Research Team for promoting NASDA's project

Purposes:

1) scientific investigations on mission requirements

2) data processing algorithms studies

3) establishment of an observation strategy for effective data acquisition (sampling problem)

4) improvement of climate prediction models by use of lidar data

Researches planned for MDS lidar experiments

Preparatory study

- Algorithms for data processing to derive quantitative information from measurement data
- Strategy for effective data acquisition to get comprehensive data set under various limitations of satellite operation

Data use study

- Radiation/cloud/aerosol interaction
- Cloud/aerosol climalotogy
- Climate modeling with use of cloud/aerosol information