Plan for a MDS-CPR Mission Project

Teruyuki Nakajima
Center for Climate System Research, the University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan
(teruyuki@ccsr.u-tokyo.ac.jp)

1. A MDS-CPR mission

We are planning to propose a cloud profiling radar (CPR) mission for the mission demonstration satellite (MDS) program of NASDA. Documents of NASDA define the MDS program as a series of small scale satellite missions for engineering and/or science demonstration with budget less than 7 B JYen with three categories, i. e., category-A for a low altitude orbit satellite with payload less than 500 kg, category-B for a 1 to 2 ton geostationary satellite, and category-C for a low altitude satellite with payload less than 100 kg. MDS-1 and -2 have been selected to be a component experiment and lidar missions, respectively. An announcement for opportunity for MDS-3 is being prepared by NASDA, that is our target for application of a spaceborne CPR mission.

The objectives of this MDS-CPR mission are to demonstrate reliability of the spaceborne CPR and effectiveness of sciences related with missions using CPR. Such a demonstration mission, along with the MDS-Lidar mission, is important to show the science feasibility of the ATMOS-B1 mission, which is a full science mission with spaceborne CPR and lidar. This paper will discuss the science issues, possible instrumentation and design of the MDS-CPR mission.

The following is a tentative configuration of the mission:

(1) Instruments: A 94 GHz CPR and a visible-IR imager

(2) Orbit: Sun-synchronous polar orbit at 10:30 is one choice in order to make combined data sets with ADEOS-2 and EOS-AM1 data, although the final specification of the orbit should be determined through a full study of orbits of planned earth observing satellites. In this regard, a capability of formation flight with a lidar satellite is interesting to pursue for extending the science of the mission.

(3) Life time: The minimum life time of 1.5 years and mean life time of 2 years are required in order to attain fundamental statistics of the cloud field with the nadir looking CPR.

(4) Science objectives: Various new studies will be performed with the spaceborne MDS-CPR.

Table 1 Specifications of the MDS-CPR mission instruments.

CPR

- f = 94GHz, dZ = 500m, nadir view
- operation mode

normal(short pulse)	H= 0-20km, 1.8kmx 5km, -23dBz
high (short pulse)	H= 0-20km, 1.8kmx10km, -26dBz
pulse compress	H= 5-20km, 1.8kmx 5km, -31dBz

Imager

- AVHRR-2 equivalent
- λ = 0.63, 0.91, 3.7, 10.8, 12.0 μm
- operation mode

  cross tracking imaging with 1km spatial resolution

Especially, studies of cloud effects on the earth's radiation budget, cloud dynamics, and water cycle are main emphases in this project.

2. Instrumentation

Table 1 shows tentative specifications of the instruments for the MDS-CPR satellite. The CPR is a single frequency (94 GHz) nadir looking spaceborne cloud profiling radar with detection limit of -31 dBz (with pulse compression mode) and with a spatial resolution of 5km x 1.8km x 0.5 km in x-y-z coordinates (along track x cross track x vertical directions). An imager is needed to estimate the 3D structure of the cloud field from CPR signals in the x-z plane. Taking into account the various conditions of the MDS-mission, such as payload, power consumption and budget, we have selected a visible-IR imager among various instruments important for assisting CPR remote sensing. A commercial type AVHRR-2 (weight of 29kg and power consumption of 29W) is a good candidate for the imager. It should be noted, however, that large band widths of AVHRR channels have brought many difficulties in quantitative remote sensing, so that it is essential to decrease the band widths as much as possible to improve remote sensing associated with the Imager. A microwave imaging radiometer is another important candidate of accompanying instruments if the condition is allowed.

3. Discussion on science issues

Table 2 lists product candidates in the MDS-CPR mission. Fundamental data from CPR are vertical profiles of the droplet backscattering coefficient, from which the statistics of cloud layering can be obtained. The statistics of top and bottom heights of cloud layers are the most important products among various statistical characteristics of cloud layering. Overlapping statistics of multi-cloud layers are another important product with CPR. It should be noted that such statistics have not been obtained in the past without a spaceborne CPR. CPR also can improve cirrus cloud detection. Almost all the present cirrus detection techniques, such as split window technique, CO_2 slicing technique and the new cirrus detection technique with 1.3 μm absorption band (Gao et al., 1993) are based on passive remote sensing techniques. According to the recent ISCCP (International Satellite Cloud Climatology Project) update, there is a large difference in the cirrus cloud amount between C1 and D1 archives over land area. Lidar and limb occultation methods are effective but there is a weak point that thick cirrus clouds could not be penetrated by such methods.

Table 2 Candidates of standard products of the MDS-CPR mission.

A. Standard products from CPR

a. top/bottom heights of cloud layers
b. corrected backscattering coeff. profile
c. cirrus detection (pattern analyses method)
d. weak rain-rate (pattern analyses method)
e. rain-rate (area integral method)

B. Day time standard products from Imager

a. cloud texture analyses to get cloud type
b. water cloud optical thickness
c. water cloud effective particle radius

C. All day standard products from Imager

a. IR-cloud texture analyses to get cloud type
b. cirrus cloud optical thickness
c. cirrus cloud effective particle radius
d. cloud top temperature
e. sea surface/land surface temperatures

D. Combined standard products (CPR+Imager)

a. cloud volume distribution
b. cirrus volume distribution
c. rain volume distribution
d. particle radius effective to entire cloud layer
e. radiation budget

Comparisons suggest that there are large differences among various global-scale precipitation estimates, especially for weak rain condition (e. g., Ferriday and Avery, 1994). IR and microwave methods have characteristic difficulties. A spaceborne CPR will contribute to improve such a situation. Pattern analyses methods can be applied to CPR signals for new rain rate estimates. In this context, it should be noted that deep convective clouds cannot be penetrated even with CPR radar. But there is an idea of extension of the area integral method, which has been applied to IR radiances, with CPR signal data even for deep convective cloud systems.

The role of the Imager is important for assisting CPR remote sensing. Horizontal imaging of clouds will provide useful information of horizontal extent of the cloud systems. The Imager also can provide many products, since there is a long history of passive remote sensing with visible-IR imagers. Cloud texture analyses with several channels will provide cloud type information. Solar radiation reflection method will give the cloud optical thickness and effective particle radius that are important information for getting the microphysical structure of the cloud

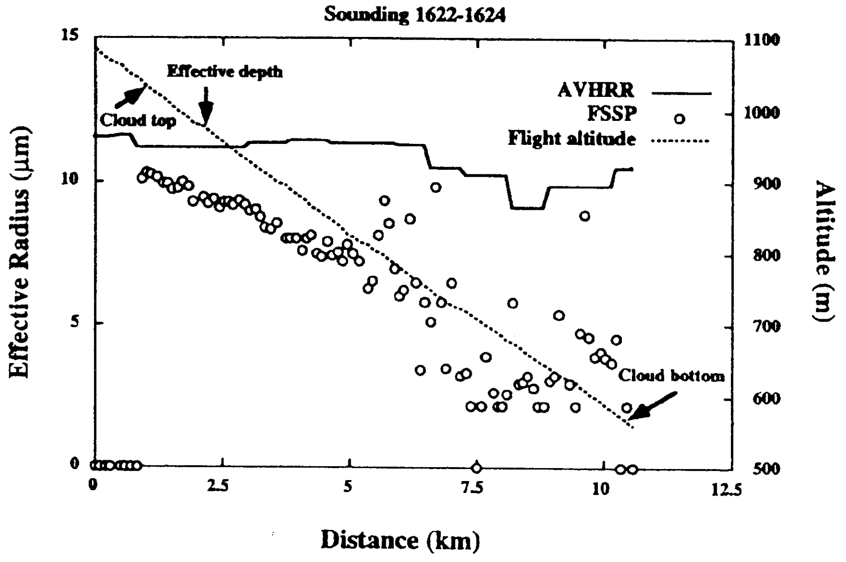

Fig. 1 The effective particle radius for a stratocumulus cloud layer (July 10, 1987, off California coast). Horizontal axis is for flight distance of an in situ measurement aircraft. The solid line shows effective particle radii retrieved from AVHRR. Open circles show in situ measured values of the effective radius by the aircraft at flight altitudes shown by dotted line. Not that the AVHRR values are for near cloud top, indicated by the effective depth. (Reproduced from Nakajima and Nakajima, 1995).

layer (Han et al.,1994; Nakajima and Nakajima, 1995). Infrared channels will provide cloud optical thickness and effective particle radius for cirrus clouds, cloud top temperature, and clear sky temperature.

New unique products can be made with the above mentioned products from CPR and Imager. The cloud volume distribution as well as rain volume distribution can be obtained by combining products concerned with horizontal and vertical extent information. Combining both the products are useful also for obtaining more accurate information of the cloud microphysical parameters such as liquid/water path and effective particle radius, since the vertical integration of respective quantities, taking into account CPR products, should be reflected in synthesized radiances that can be compared with radiances of the Imager. Figure 1 shows a large vertical inhomogeneity of the effective particle radius of a stratocumulus cloud layer and that passive remote sensing values of the effective particle radius are corresponding to near cloud top values. In return, it is possible to solve the radar equation with the optical thickness and effective particle radius near cloud top, retrieved from the Imager, as an initial condition. For highly broken cloud systems, it is interesting to find a parameterization of broken cloud effects with radar data and Imager radiances. It should be pointed out that the main objective of the mission is not to provide detailed 3D cloud structure, but to provide statistical products for climate studies. It is, therefore, natural to adopt various composite methods (e. g. Lau and Crane, 1995; Mace et al., 1997) for obtaining meaningful statistics for cloud systems.

We need to consider the requirement for the orbit. Polar orbit will be most useful for us, since the CPR is useful for cloud and weak rain detection in high latitudes. Sun-synchronous orbit is adopted from a consideration to increase global sampling rate with the short life time and non-scanning nadir looking performance of the CPR. The local time of 10:30 is one of candidates because of many other platforms at that time such as EOS-AM1 and ADEOS-2.

4. Conclusions

The MDS-CPR mission, as described in the preceding sections, looks promising as a precursor of the ATMOS-B1 mission, which is a full science mission with CPR, lidar and imagers. It has been recognized that there are several significant improvements if we have a lidar with a CPR. Recent studies suggest that a CPR is not enough to detect all the cloud systems radiatively important. Especially noticeable amount of thin cirrus and broken clouds will not be detected by a CPR. A lidar will provide complementary data in such cases, whereas a lidar cannot penetrate thick clouds. Combining CPR and lidar data is also useful to perform a precise determination of effective particle radius as a function of height, since signals for the former are proportional to r^6 with particle radius r and signals for the latter are proportional to r^2 as shown by Fig. 2 (Nakajima, 1995). Furthermore, more concrete studies of cloud-aerosol interaction will be possible if we combine lidar aerosol signals and aerosol distribution obtain by an imager

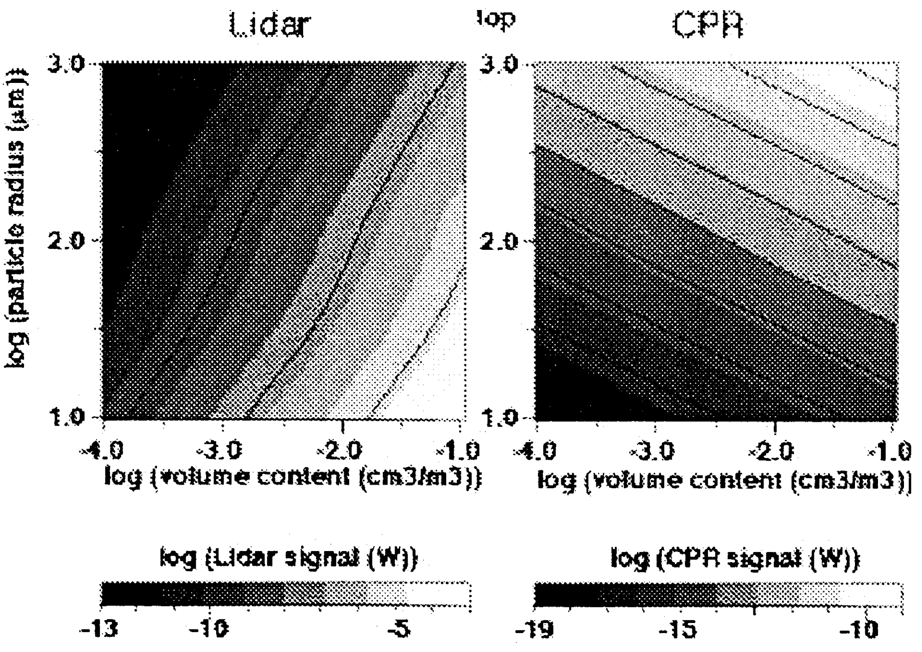

Fig.2 A simulation of Lidar and CPR signals (W) at the cloud top as a function of ice volume content and particle radius. Cases of cirrus clouds with cloud top height of 10 km. (Reproduced from Nakajima, 1995).

(Higurashi and Nakajima, 1998).

Despite of such insufficient aspects without lidar, it is obvious that the MDS-CPR mission can provide an innovative new data for climate studies.

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