Cloud-Radiation Study in the JACCS/MRI Program

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CLOUD-RADIATION STUDY IN THE JACCS/MRI PROGRAM

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1. INTRODUCTION

The Japanese Cloud and Climate Study (JACCS) program is a Japanese research effort focusing on the problems associated with issues related to cloud-radiation interactions. It is one of ten-year long (FY1991-2000) climate research programs sponsored by the Japanese Science and Technology Agency. Major scientific objectives of the JACCS program are to (1) advance our understanding of the relationship between micro-physical properties, the macro-physical structures and the radiative properties of various mid-latitude clouds; (2) develop advanced uses of satellite data in the cloud-climate study; and (3) develop better parameterization of radiation and cloud processes used in GCMs. About 40 researchers are involved in the JACCS program mostly from the Meteorological Research Institute (MRI) and from three other national institutes.

The JACCS/MRI program includes such research activities as field experiment on cloud-radiation processes, satellite data analyses, and numerical modeling of radiation and cloud processes. Two types of field experiment are being conducted for various mid-latitude clouds around Japan; one involves ground-based observations of high-level ice clouds (no direct aircraft measurements available) associated with fronts in spring to early summer seasons. The other is aircraft observations for stratiform water and mixed-phase clouds in winter seasons. Here, we will focus our discussion on the cloud-radiation observing system and some preliminary results obtained through the field campaigns held in the JACCS/MRI program.

2. GROUND-BASED CIRRUS OBSERVING SYSTEM

The main purpose of the ground-based cirrus experiment is to obtain simultaneous observational data on cloud-microphysical and radiative properties, and to study the relationship between them for ice clouds associated with mid-latitude fronts. We have organized a synthetic ground-based observing system at MRI, Tsukuba (36.0N, 140.1E), Japan. The system involves the combined sonde (cloud-particle-video-sonde + radiation-sonde) system, a cloud-lidar, a Doppler radar, a windprofiler, a microwave radiometer, and various types of spectro-radiometers as well as several conventional pyranometers and pyrgeometers.

We can obtain various information on the cloud structures and radiative properties such as cloud-height and thickness measured by the cloud lidar, spectral solar and infra-red (IR) zenith radiance by the spectro-radiometers, and the solar and IR fluxes at the surface. In addition, cirrus optical thickness in the solar spectral region can be obtained from sunphotometery (Shiobara and Asano, *JAM*, **33**, 672, 1994; Shiobara et al., *JAM*, **35**, 36, 1996). The FT-IR spectral data can be used to infer IR optical thickness and effective ice-particle sizes. The cloud-microphysical properties can be measured by using Cloud-Particle-Video-Sonde (CPVS), that is a modified version of the MRI Hydrometeor-Video-Sonde (Murakami and Matsuo, *JAOT*, **7**, 613,1990) and improved to get a higher resolution and a larger sampling volume in tenuous ice clouds. We can measure vertical distributions of the solar and IR radiative fluxes as well as air-temperature and humidity by using radiation-sonde newly developed at MRI. A combined-sonde observing system has been developed by connecting a radiation-sonde and a CPVS in series to a balloon in order to simultaneously measure the microphysical, thermodynamic and radiative properties of ice clouds. These observational data, along with concurrent NOAA polar-orbit satellite data, are being analyzed to study ice cloud-radiation interactions.

3. RESULTS FROM THE GROUND-BASED OBSERVATION

Intensive ground-based observations are being carried out during April through June in 1995 to 1998 for mid-latitude frontal ice-clouds. We have obtained several observational data sets of good quality for frontal cirrostratus cases. Here, we will show some preliminary results obtained from the combined-sonde launched to the cirrostratus cloud observed on 7 May 1996. Figure 1 shows the vertical profiles of the air temperature and humidity as well as wind, measured by a rawinsonde built in the radiation-sonde. The cirrostratus cloud was associated with a warm front of a weak cyclone, and it extended from about 6km up to 11.5km (tropopouse) at that time. The cloud-base height at 10:43JST of the sonde launching was also detected to be 5.9km by the cloud lidar. Figure 2 shows an example of ice-crystal images taken by the microscopic camera of the accompanied CPVS at altitude of 6.1km (-18°C) near the cloud-base. By analyzing these image data we can evaluate microphysical properties of the cirrostratus cloud. Foe example, Figure 3 shows the vertical profiles of ice-water-content and ice-crystal concentration. The integrated ice-water-path was estimated to be $27 g/m^2$ for the sonde path. We have also evaluated the ice- crystal size distributions and the altitude (temperature) distribution of the relative abundance ratios of different crystal habits in the cirrostratus cloud. Solid columnar and bullet-like crystals and their rosette crystals were dominant in the upper part of the cloud layer with lower temperatures. On the other hand, the abundance of plate crystals increased in the lower part with temperatures warmer than -35°C.

The corresponding profiles of the downward and upward fluxes of the shortwave and longwave radiation are shown in the top and bottom panels of Figure 4, respectively. The solar reflectance and transmittance were estimated to be 0.27 ± 0.02 and 0.62 ± 0.02, respectively, for the cirrostratus layer at the solar zenith angle about 20°. On the other-hand, the IR effective emittance was estimated to be 0.85 ± 0.05. Further, the solar and IR radiative heating rates were evaluated by smoothing the net flux profiles drawn in Fig. 4. The cloud layer was strongly heated by absorption of the solar radiation. The cloud-bottom layer was also heated by absorption of the IR radiation from the surface, however, the cloud-top layer was cooled by emission of IR radiation to space.

4. AIRCRAFT OBSERVATION

Simultaneous and collocated observations of clouds and radiation are planned by using multiple aircraft for stratiform low-level clouds around Japan Islands during FY1995-FY1997. Synchronized flight by two aircraft is our essential strategy for examining radiation budget of cloud layers. For radiation remote-sensing measurement, we use a Cessna 404 Titan aircraft equipped with a dual-channel microwave radiometer, an FT-IR spectrometer, and a multichannel-cloud-pyranometer (MCP) system developed by Asano et al.(*JOAT*,**12**,479, 1995) as well as conventional flux radiometers. For *in-situ* cloud measurements, on the other hand, we employ a Beechcraft B200 Super King Air equipped with various instruments such as a video-microscope system for sizing cloud droplets developed at MRI (Tanaka et al., *Atm. Res.*, **24**, 71, 1989), a set of PMS FSSP and 2D-C probe, a Gerber's microphysics probe, a wind probe, a Lyman-a hygrometer, as well as a set of flux radiometers. The aircraft platforms are available from a commercial air service company. We have cross-checked the performances of these instruments through the preliminary field experiment in January 1996 for wintertime stratocumulus clouds over the Sea of Japan, and confirmed good performance of the JACCS Airborne Cloud-Radiation Observing System (ACROS). For example, Figure 5 compares the cloud liquid water paths measured by the microwave radiometer with those evaluated with the cloud optical thickness and effective cloud particle radii retrieved from spectral solar reflectances measured by the MCP system (Asano et al., *JAS*, **52**, 3556, 1995). The cloud microphysical properties measured by different probes were coincident within accuracy of each instrument. Intensive field campaigns are scheduled in Januarys of 1997 and 1998 for wintertime stratocumulus clouds over the sea around the South-West Islands area.

5. CONCLUDING REMARKS

In the JACCS/MRI program, we are operating two types of field experiments of the ground-based ice-cloud observations and aircraft water cloud observations during FY1995 through FY1997. Here, the outline and the state of the art of the JACCS field observing systems are reported. Several unique instruments have been developed at MRI in the JACCS program. For example, the newly developed sonde system has proved to be very effective for simultaneous measurements of detailed vertical distributions of the cloud microphysical properties and radiation fluxes for high-level ice clouds. On the other hand, the sonde observations involve some serious limitations or shortages such as poor representativeness for horizontally inhomogeneous clouds. A combination of aircraft measurement and sonde observation will be a useful and potential way to investigate highly inhomogeneous clouds.

The observational data obtained through the JACCS field experiment for midlatitude clouds will be valuable for the study of cloud-radiation interaction processes. Specific researches using these data will yield interesting and fruitful results.

Acknowledgments. JACCS is supported by the Science and Technology Agency of Japanese Government. Thanks are due to Dr. M. Shiobara for his great effort in building ACROS and to my many colleagues for their cooperation and contributions to the JACCS field experiment. The sonde observation is kindly assisted by the JMA TATENO Aerological Observatory, Tsukuba. The aircraft observation is assisted by Nakanihon Air Service Co. (Nagoya). The JACCS WWW home-page is located at the following URL: http://www.mri-jma.go.jp/Proj/JACCS/jaccs.html.

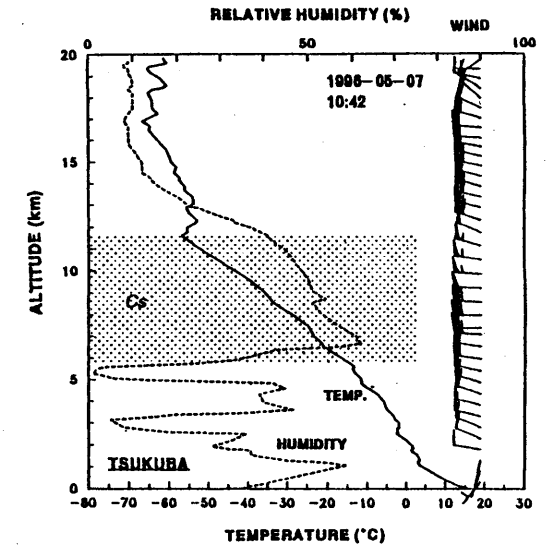

Fig. 1. Altitude distribution of the air-temperature, relative humidity and wind measured by a rawinsonde built in the radiation-sonde launched at 10:43(JST) on 7 May 1996.

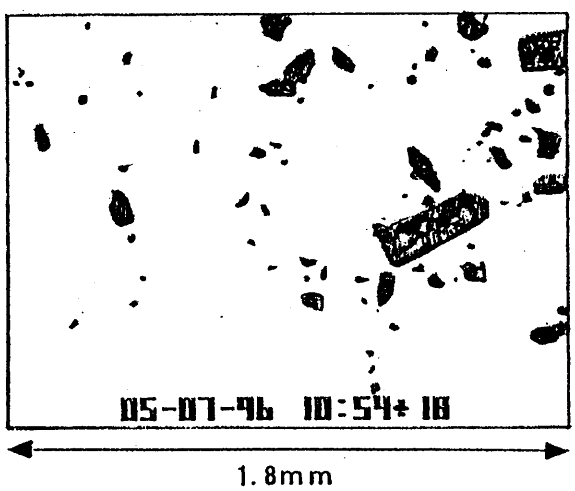

Fig. 2. Example of ice-crystal images taken by a microscopic camera of the cloud-particle-video-sonde at 6.1km (18°C) in the cirrostratus cloud observed on 7 May 1996.

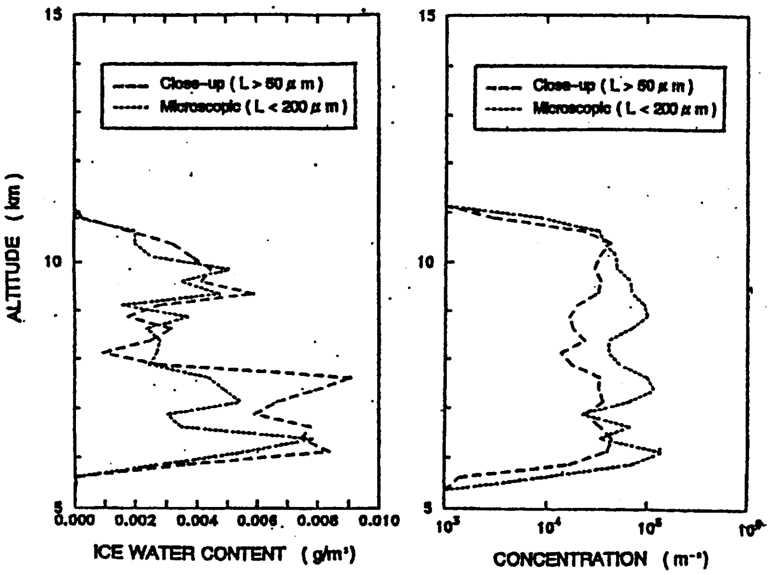

Fig. 3. Vertical profiles of the ice-water-content (**LEFT**) and ice-crystal concentration (**RIGHT**) measured by a cloud-particle-video-sonde launched at 10:43(JST) to cirrostratus cloud observed on 7 May 1996.

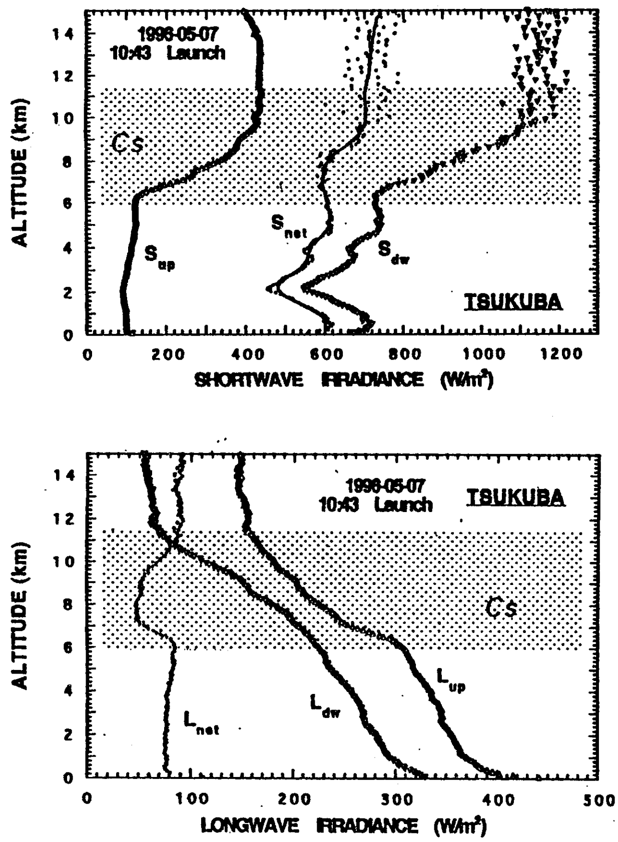

Fig. 4 Altitude distribution of the downward and upward fluxes of the shortwave radiation (**TOP**) and the longwave radiation (**BOTTOM**), respectively, measured by the accompanied radiation-sonde for the same case as Fig. 3. The net fluxes defined as differences of the upward fluxes and downward fluxes are also plotted. The solar zenith angle was about 20°.

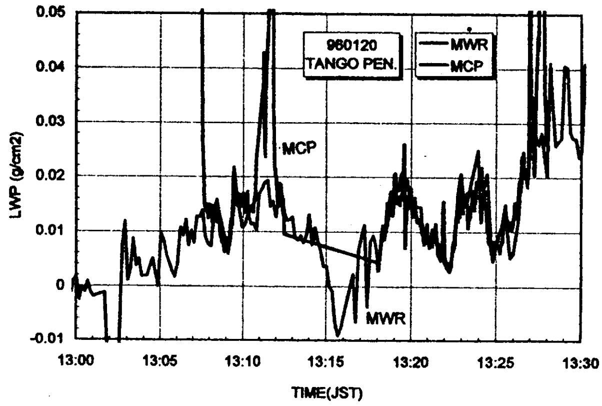

Fig. 5 Comparison of cloud liquid-water-path (LWP) measured by a dual-frequency microwave radiometer (MWR) and estimated from the spectral solar reflectance measured by the multichannel cloud pyranometer system (MCP), on board C404 flying at the altitude 3000m, on January 1996.

Int'l Workshop Spaceborne Lidar'96 (Hakone, 1996.12.16-18)

CLOUD-RADIATION STUDY IN THE JACCS/MRI PROGRAM*

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CONTENTS:

1. JACCS(Japanese Cloud-Climate Study) Program
2. JACCS Field Experiment
   1) Ground-based Ice-Cloud Observation
   2) Aircraft Water (Mixed-phase) Cloud Observation

* http://www.mri-jma.go.jp/Proj/JACCS/jaccs.html

JAPANESE CLOUD-CLIMATE STUDY*
(FY1991 - FY2000)

JACCS Central Objectives are to;

a) Advance our understanding of the cloud-radiation interaction processes,
b) Advance our understanding of the physical / dynamical processes of clouds and large-scale cloud systems,
c) Improve the currently used remote sensing methods to retrieve cloud and radiation parameters from space and the ground,
c) Improve the parameterizations of cloud and radiation processes used in climate models.

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* Sponsored by the Science and Technology Agency of the Japanese Government

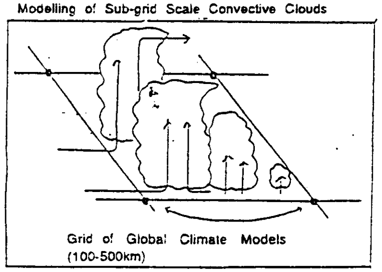
JACCS* (JApanese Cloud-Climate Studies) : The MRI Program (FY1991 ~ FY2000)

(* Sponsored by the Science and Technology Agency)

Numerical Modeling of Clouds

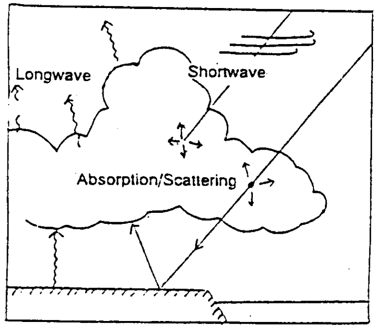
- Modelling of Formation/Developing Processes of Clouds

Modelling of Sub-grid Scale Convective Clouds

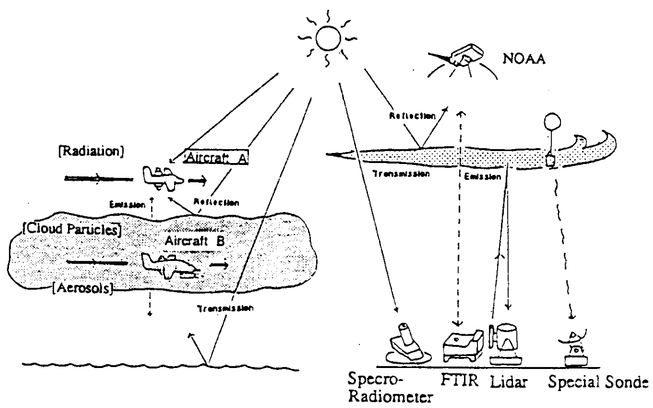


- Modelling of Radiative Processes of Clouds

Modelling of Radiation Processes in Realistic Cloudy Atmosphere-Surface Systems.

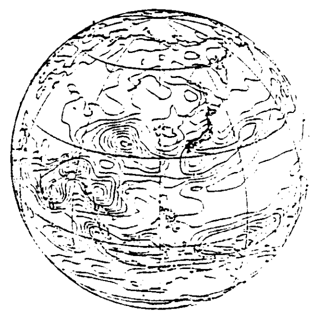


Observations of Clouds and Radiation



- Aircraft Observation of Low- and Middle-level Clouds
- Ground-based Observations of Ice Clouds

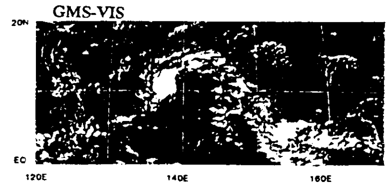
Improvement and Validation of Global Climate Models

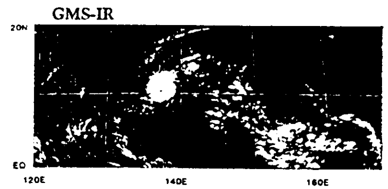


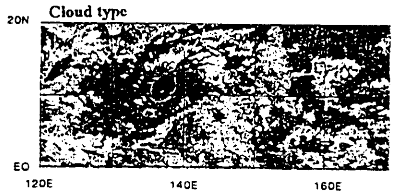
goal: Development of A Global Warming Prediction Model which Properly Incorporates Cloud-Radiation Effects.

Satellite Data Analysis and Cloud Climatology

- Cloud parameter retrievals
- Radiation budget analysis
- Cloud Classification and Distributions







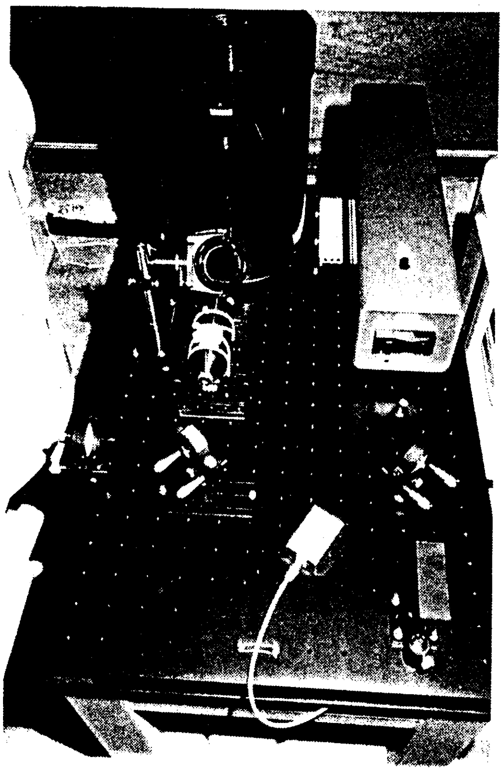
INSTRUMENTATION FOR THE GROUND-BASED CIRRUS OBSERVATION

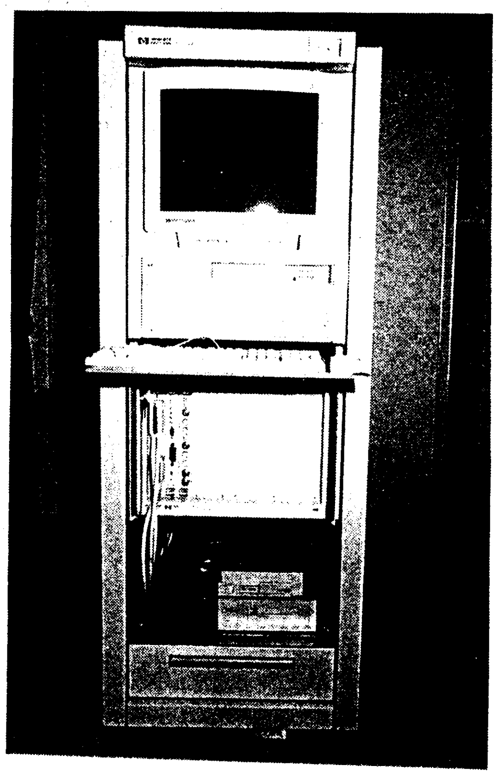
INSTRUMENTS	WAVELENGTH	MEASURED QUANTITY	EXTRACTED PHYSICAL PARAMETERS
[Sonde]			
Radiation Sonde* + (Rawin Sonde)	0.3–3 μ m 4–50 μ m	up/down solar fluxes up/down longwave fluxes P,T,H	Vertical profile of the upward/downward fluxes of the solar and terrestrial radiaton Vertical profile of temperature and humidity
Cloud Video Sonde* (improved HYVIS)		images of ice crystals	Cloud microphysical parameters (cloud particle size, shape, phase, number density, and ice water content)
[Lidar]			
MRI Cloud lidar*	532 nm (YAG)	backscattering ratio depolarization	Cloud base/top heights, optical thickness, cloud particle phase, and vertical structure
CRL CO_2 lidar	10.6 μ m	backscattering coefficients	Cloud IR reflectivity
[Radiometer]			
Sunphotometer	368, 421, 502 676, 864, 938 938, 1050 nm	spectral attenuation of the direct solar radiation	Spectral cloud optical thickness, Column water vapor amount
Multichannel sky-scanning photometer*	367, 500, 676 943, 1021,1650, 2220 nm	sky radiance/polarization	Effective particle size, scattering phase function
Multichannel-Cloud -Pyranometer*	420,500,675,760 862,938,1080 1225,1650 nm	spectral solar flux	Spectral solar flux at the surface
Spectroradiometer	0.4–2.0 μ m	spectral solar radiance	Spectral transmissivity and optical thickness
FT-IR spectrometer	800–1200 cm^{-1}	spectral zenith IR radiance	Spectral effective emissivity, IR optical thickness
IR Radiation-thermometer	9.5–11.5 μ m	brightness temperature	Cloud effective temperature, effective emissivity
Pyranometers	0.3–3 μ m 0.7–3 μ m	broad-band solar flux broad-band solar flux	Broad-band total solar flux Broad-band near-IR solar flux
Pyrgeometer	4–50 μ m	longwave flux	Broad-band atmospheric radiative flux
Microwave -radiometer	22GHz, 37GHz	brightness temperature	Column water vapor amount, and column liquid water content
[Other Remote Sensor]			
Wind-profiler	404 MHz	wind speed and direction	Vertical profile of wind field
Radar	X-band	profile of Z	Cloud structure
CCD TV camera		whole sky image	Monitoring of cloud distribution
[Satellite]			
NOAA	AVHRR, HIRS	visible reflectance brightness temperature	Cloud distribution, cloud type, optical thickness, emissivity
GMS	Vis, IR	cloud image	Cloud distribution and movement

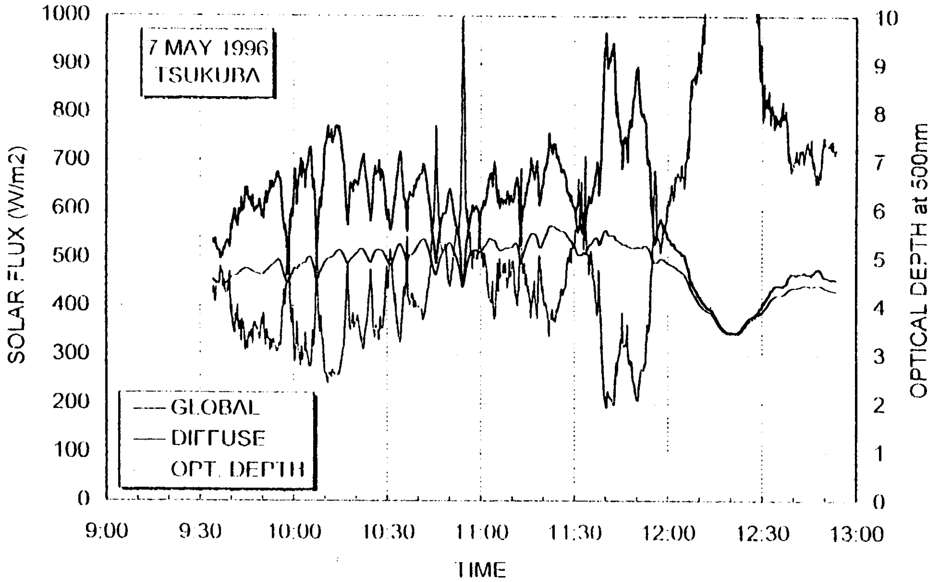
* Developed by the MRI

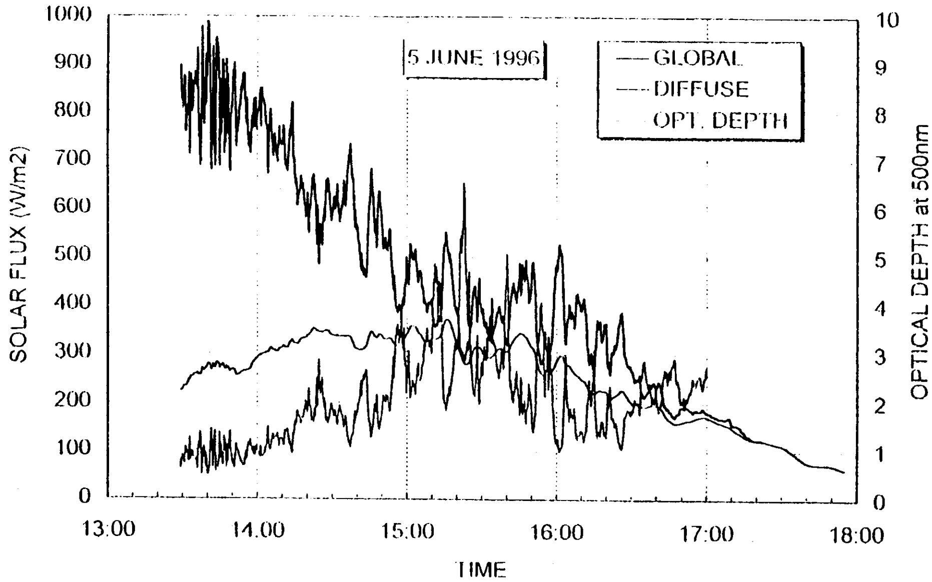
MRI CLOUD LIDAR

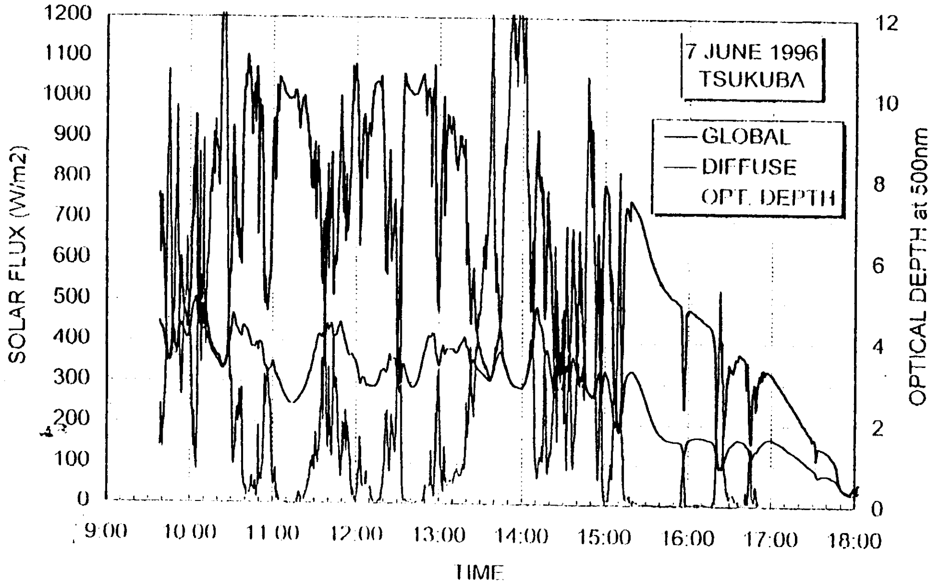
Wavelength	532 nm (SHG Nd: YAG)
Pulse energy	300 mJ
Pulse repetition	10 Hz
Beam divergence	1.1 mrad
Telescope diameter	250 mm Φ
Telescope type	Schmidt cassegrain
Field of view	3.0 mrad
Polarization	P and S
Gate width	6 m minimum, 96 m nominal
Signal processing	Photon counting

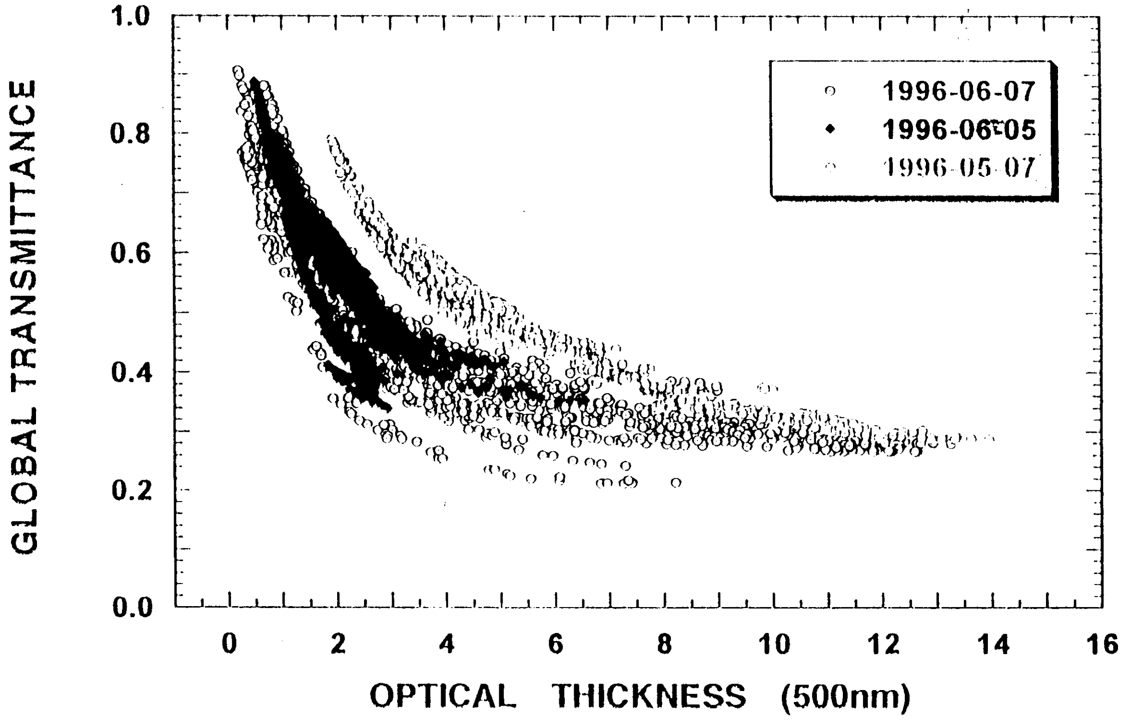


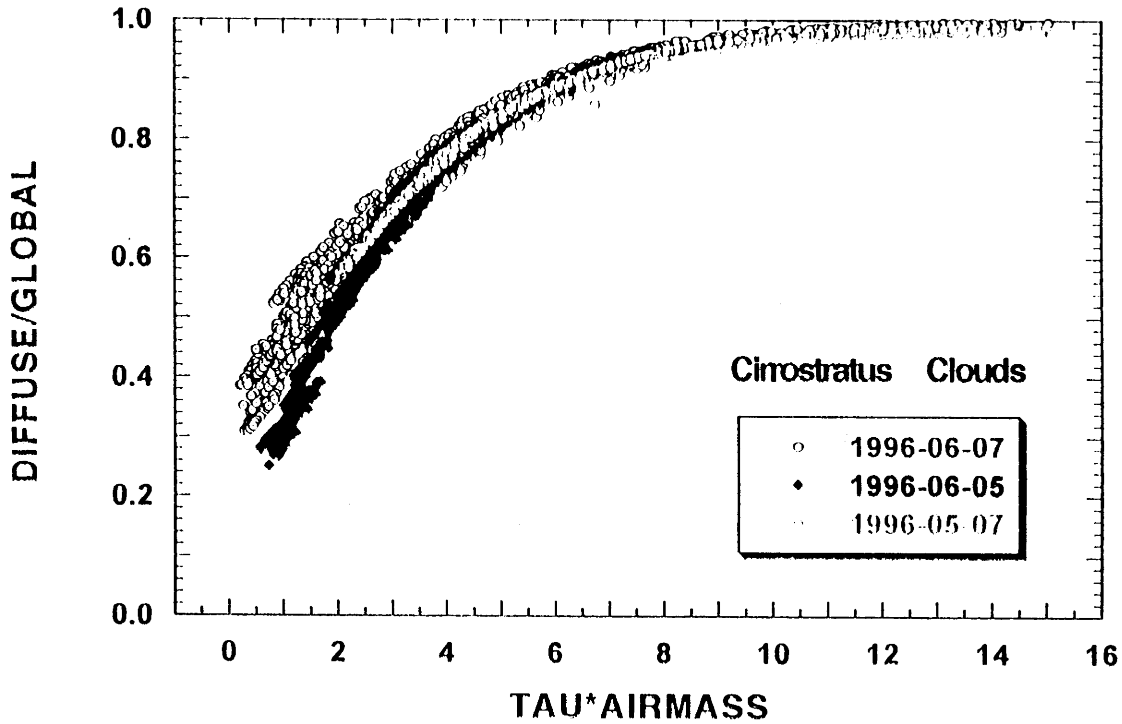



7 MAY 1996
TSUKUBA
GLOBAL
DIFFUSE
OPT. DEPTH
SOLAR FLUX (W/m2)
OPTICAL DEPTH at 500nm
TIME

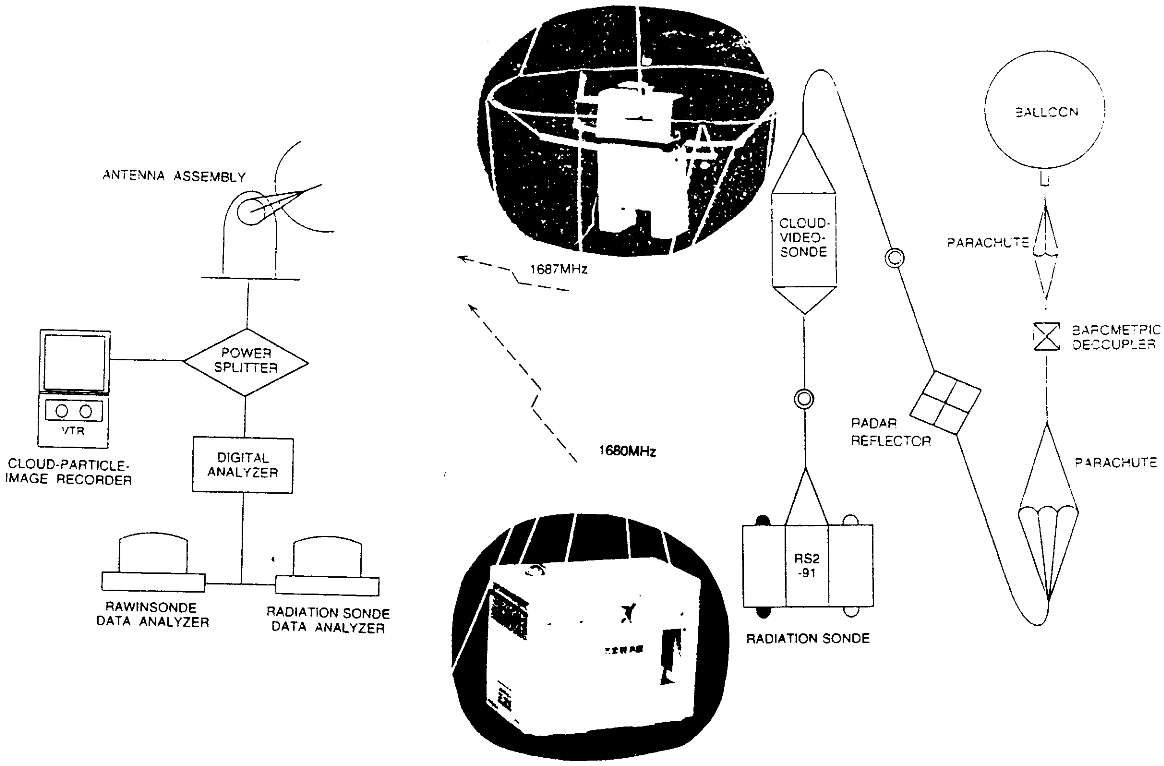

5 JUNE 1996
GLOBAL
DIFFUSE
OPT. DEPTH
SOLAR FLUX (W/m2)
OPTICAL DEPTH at 500nm
TIME

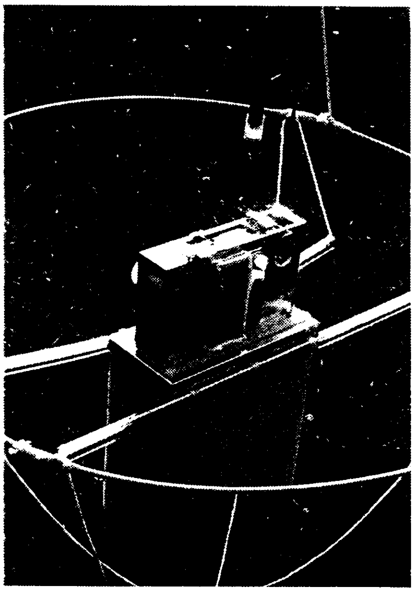

7 JUNE 1996
TSUKUBA
GLOBAL
DIFFUSE
OPT. DEPTH
SOLAR FLUX (W/m2)
OPTICAL DEPTH at 500nm
TIME

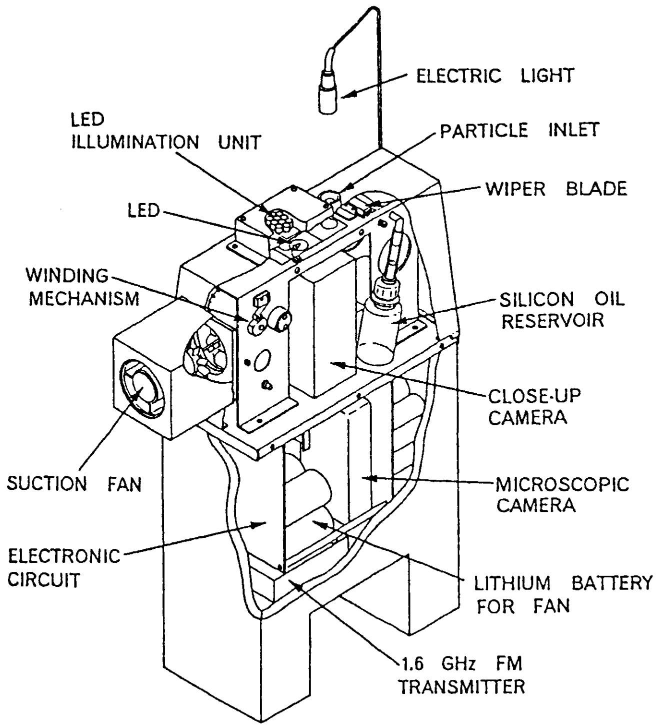

1.0
0.8
0.6
0.4
0.2
0.0
GLOBAL TRANSMITTANCE
0
2
4
6
8
10
12
14
16
OPTICAL THICKNESS (500nm)
1996-06-07
1996-06-05
1996-05-07


1.0
0.8
0.6
0.4
0.2
0.0
DIFFUSE/GLOBAL
0
2
4
6
8
10
12
14
16
TAU*AIRMASS
Cirrostratus Clouds
1996-06-07
1996-06-05
1996-05-07

Sonde Observation System for Ice Clouds

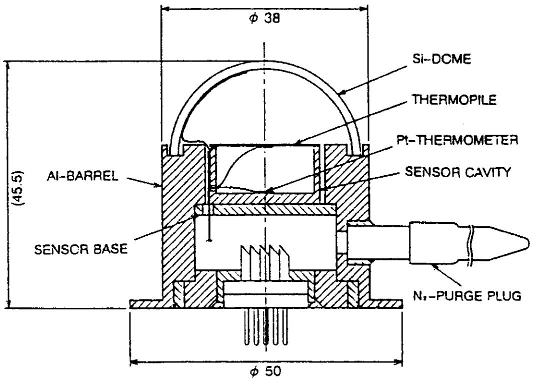




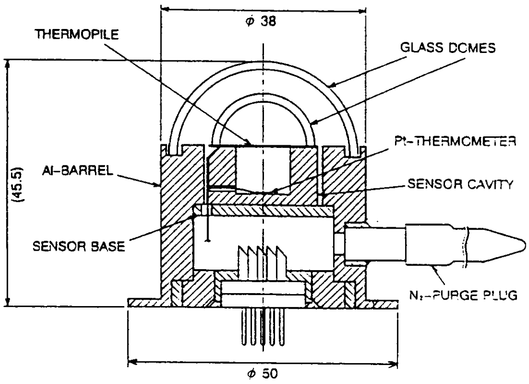


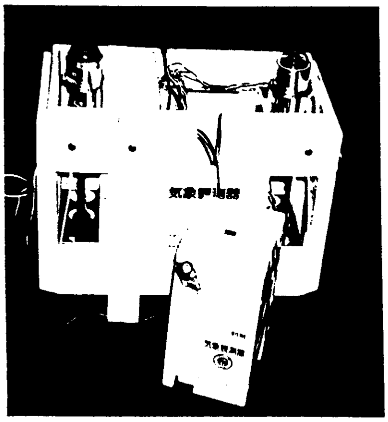
Cutout view of the new version of HYVIS (Ice-Particle-Video-Sonde) [Orikasa et al.,1996]

LONGWAVE RADIOMETER

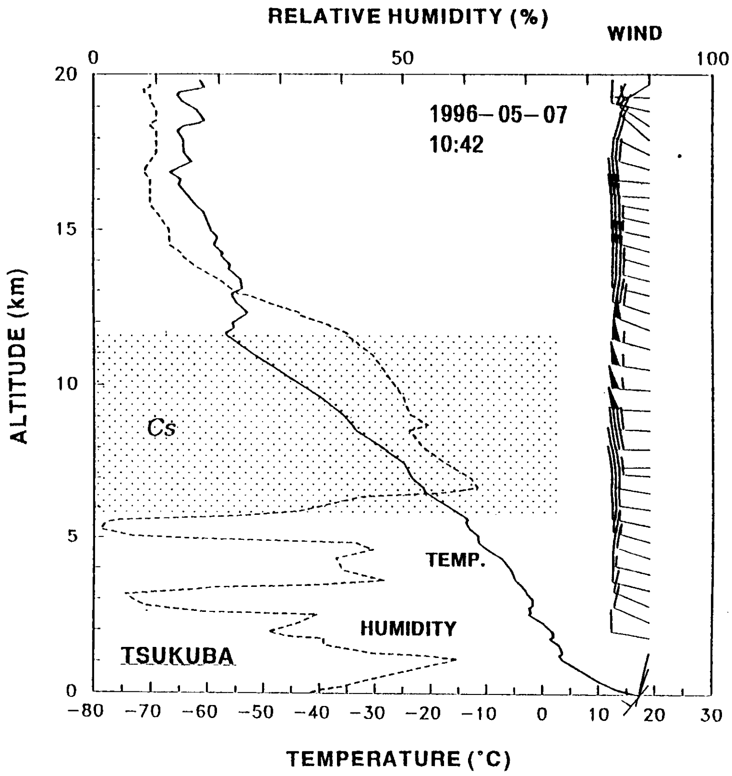


SHORTWAVE RADIOMETER





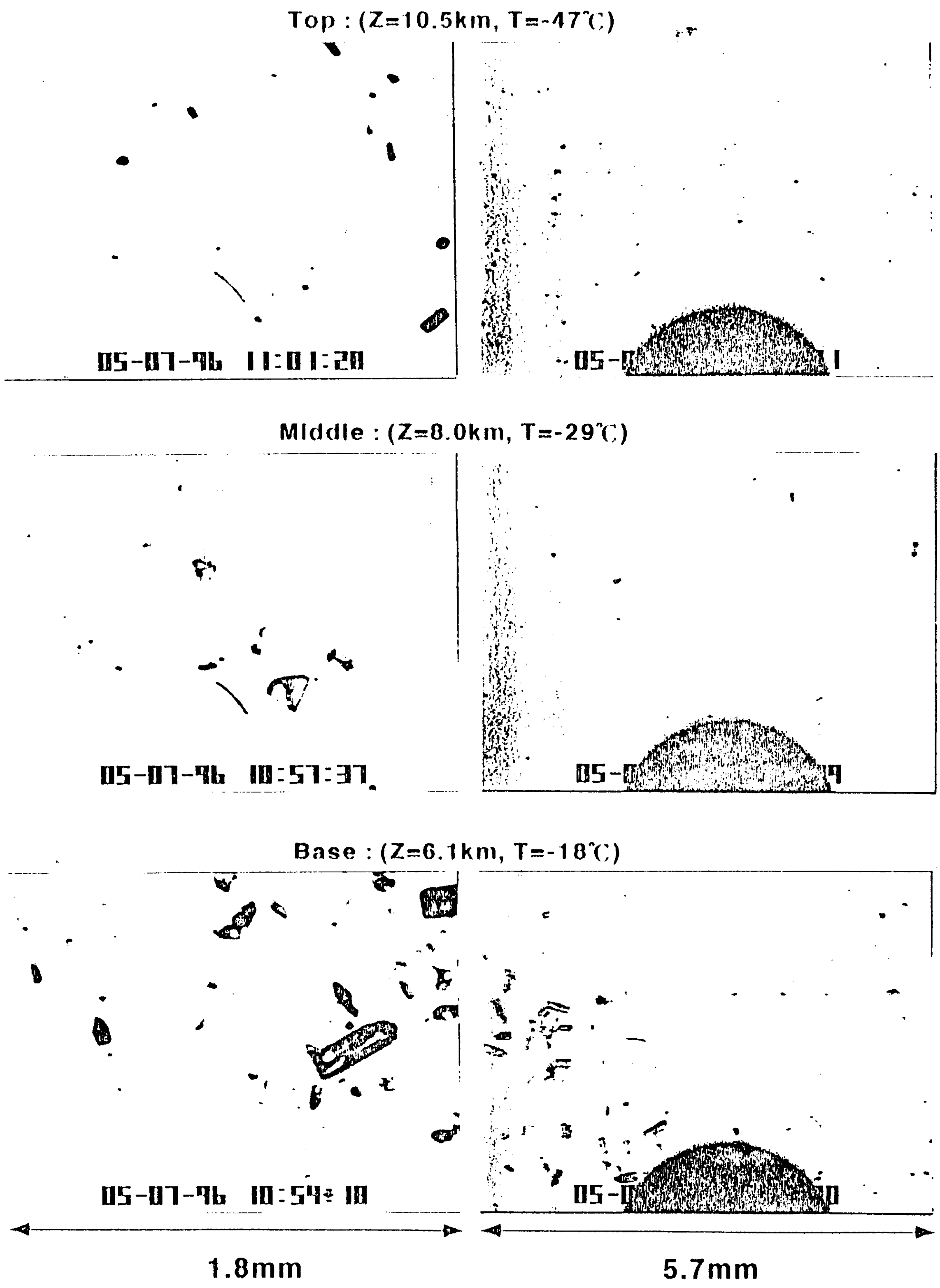
RS2-91 RAWIN-SONDE



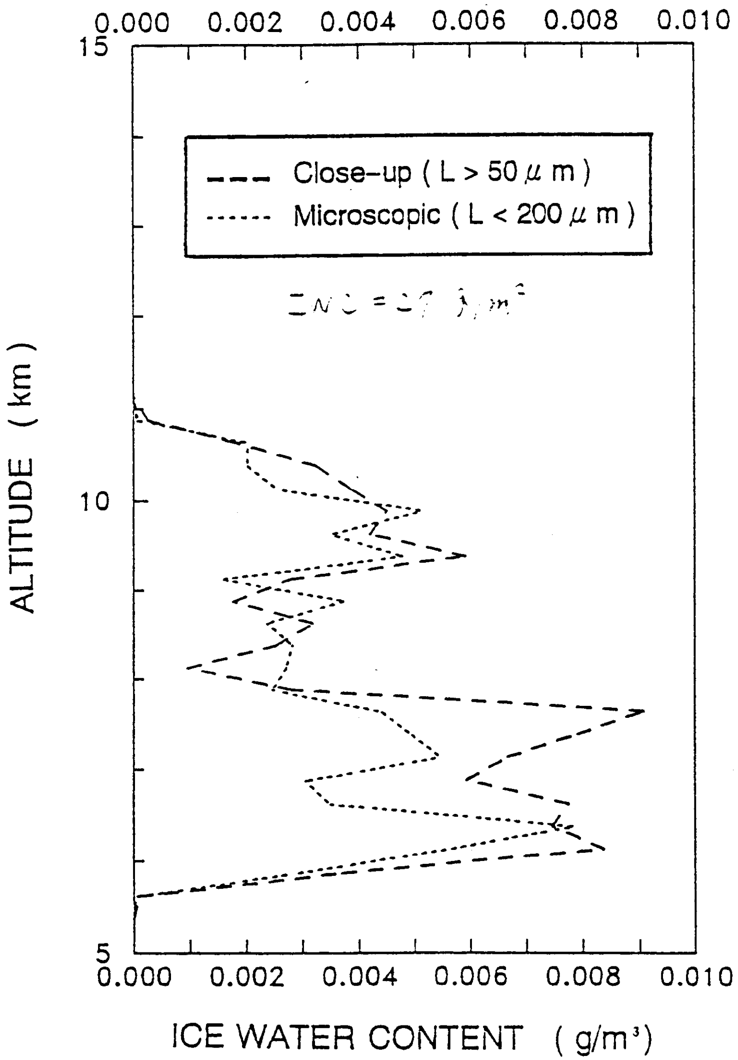
Ice Crystals Observed by Cloud-Particle-Video-Sonde

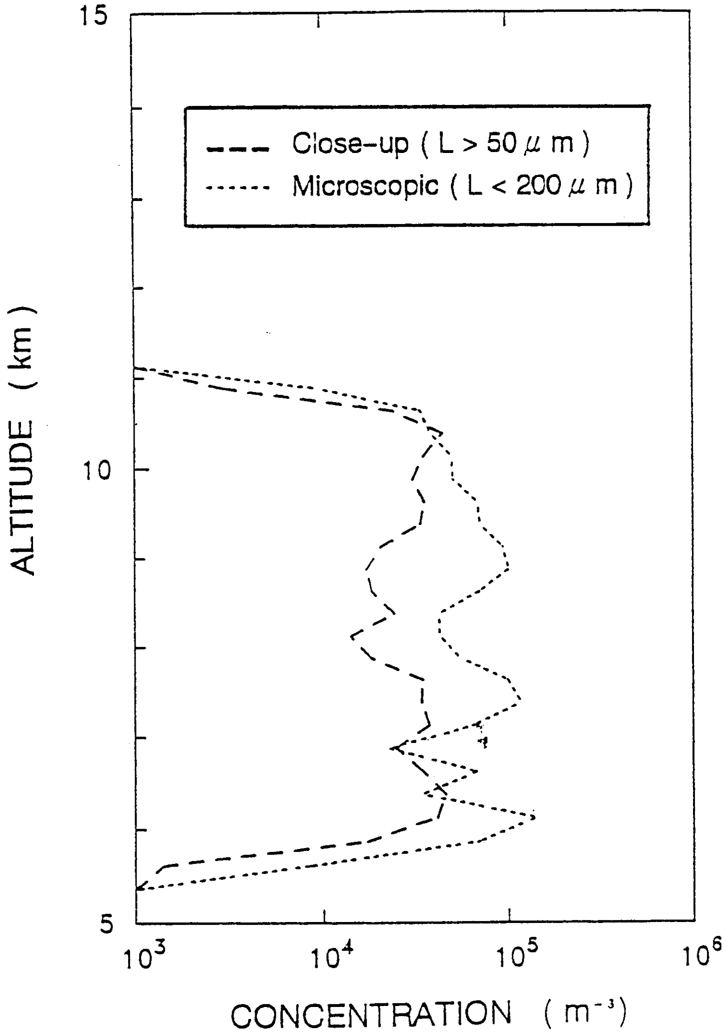
(1996-05-07: Cirrostratus)

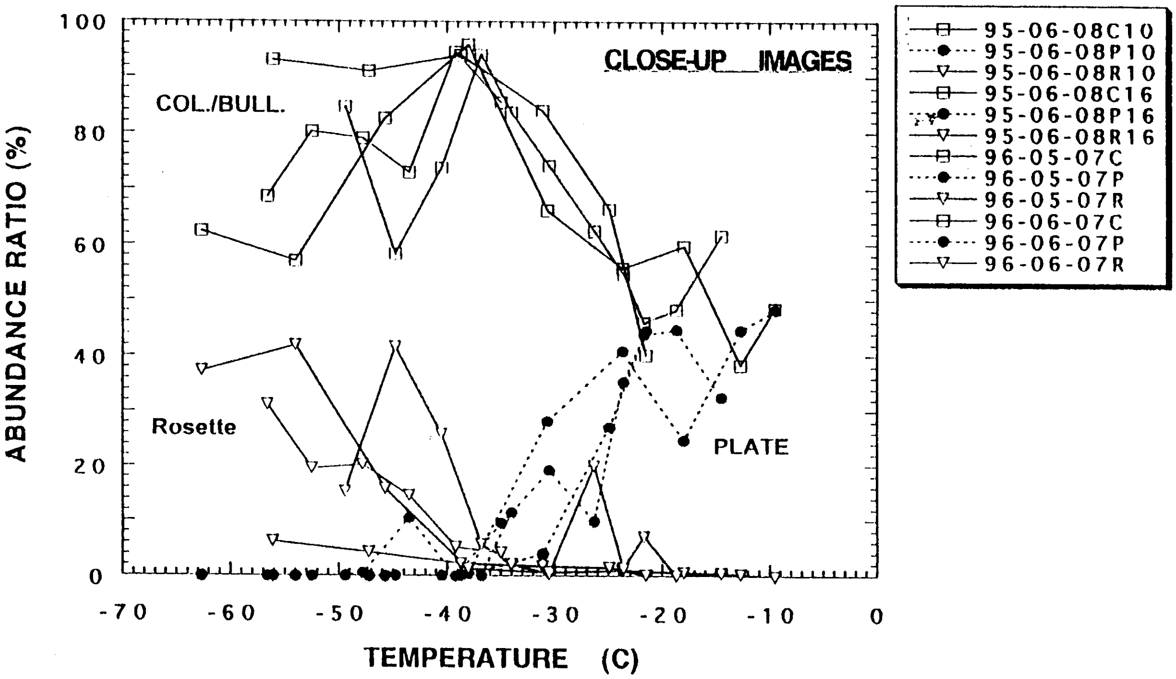
Microscopic Images **Close-up Images**



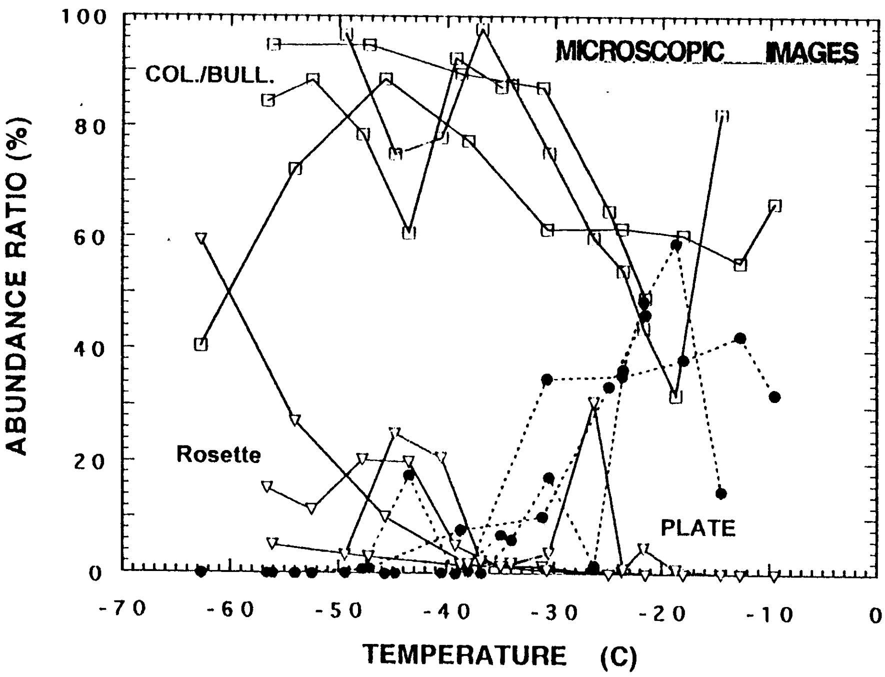
1996- 05- 07 10:42 (Tsukuba) Cirrostratus





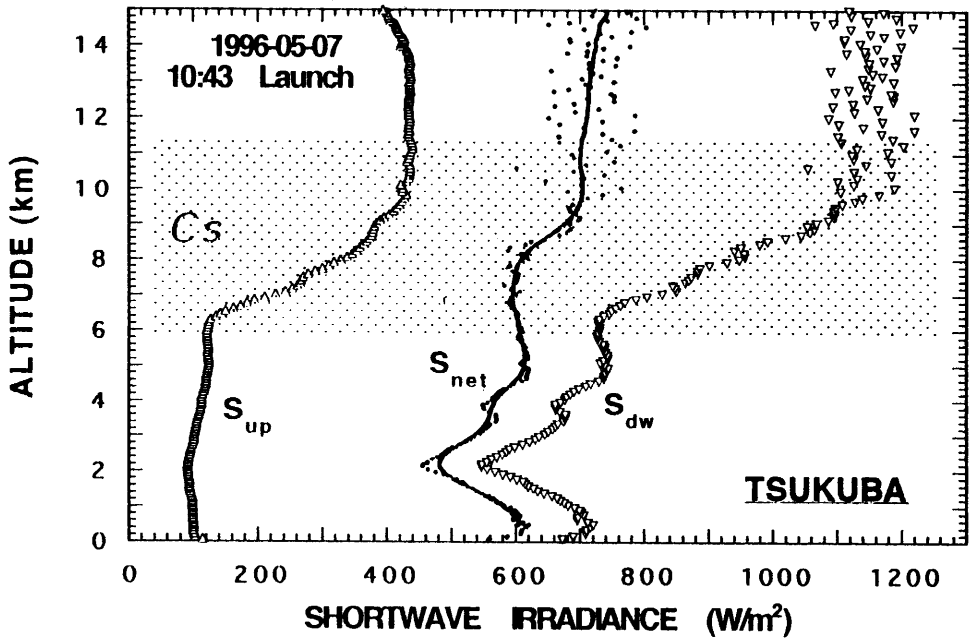


100
80
60
40
20
0
-70
-60
-50
-40
-30
-20
-10
0
ABUNDANCE RATIO (%)
TEMPERATURE (C)
CLOSE-UP IMAGES
COL./BULL.
Rosette
PLATE
95-06-08C10
95-06-08P10
95-06-08R10
95-06-08C16
95-06-08P16
95-06-08R16
96-05-07C
96-05-07P
96-05-07R
96-06-07C
96-06-07P
96-06-07R



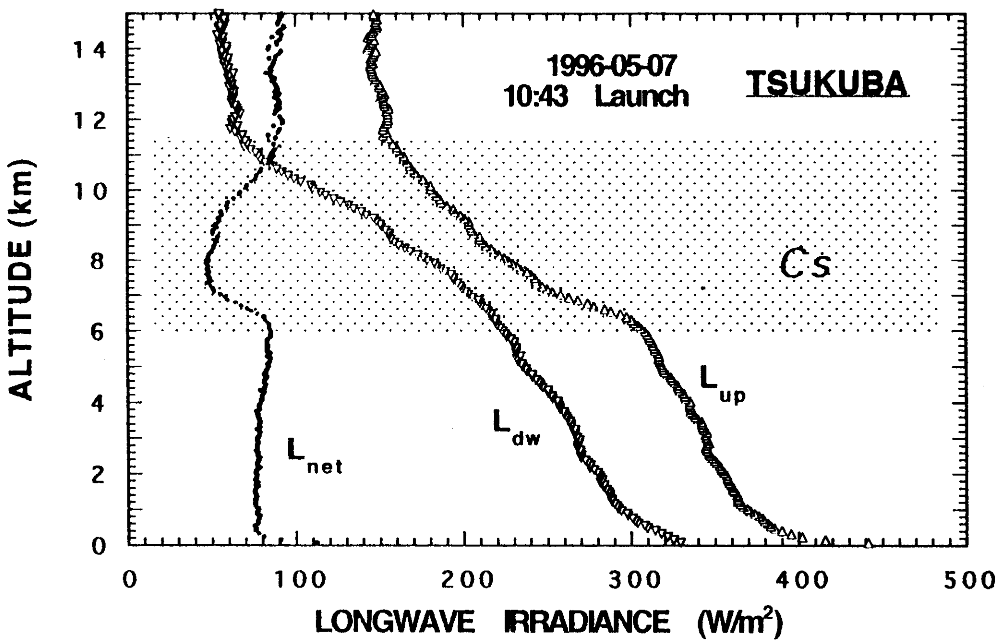
100
80
60
40
20
0
-70
-60
-50
-40
-30
-20
-10
0
ABUNDANCE RATIO (%)
TEMPERATURE (C)
MICROSCOPIC IMAGES
COL./BULL.
Rosette
PLATE

$\theta_0 \simeq 20°$

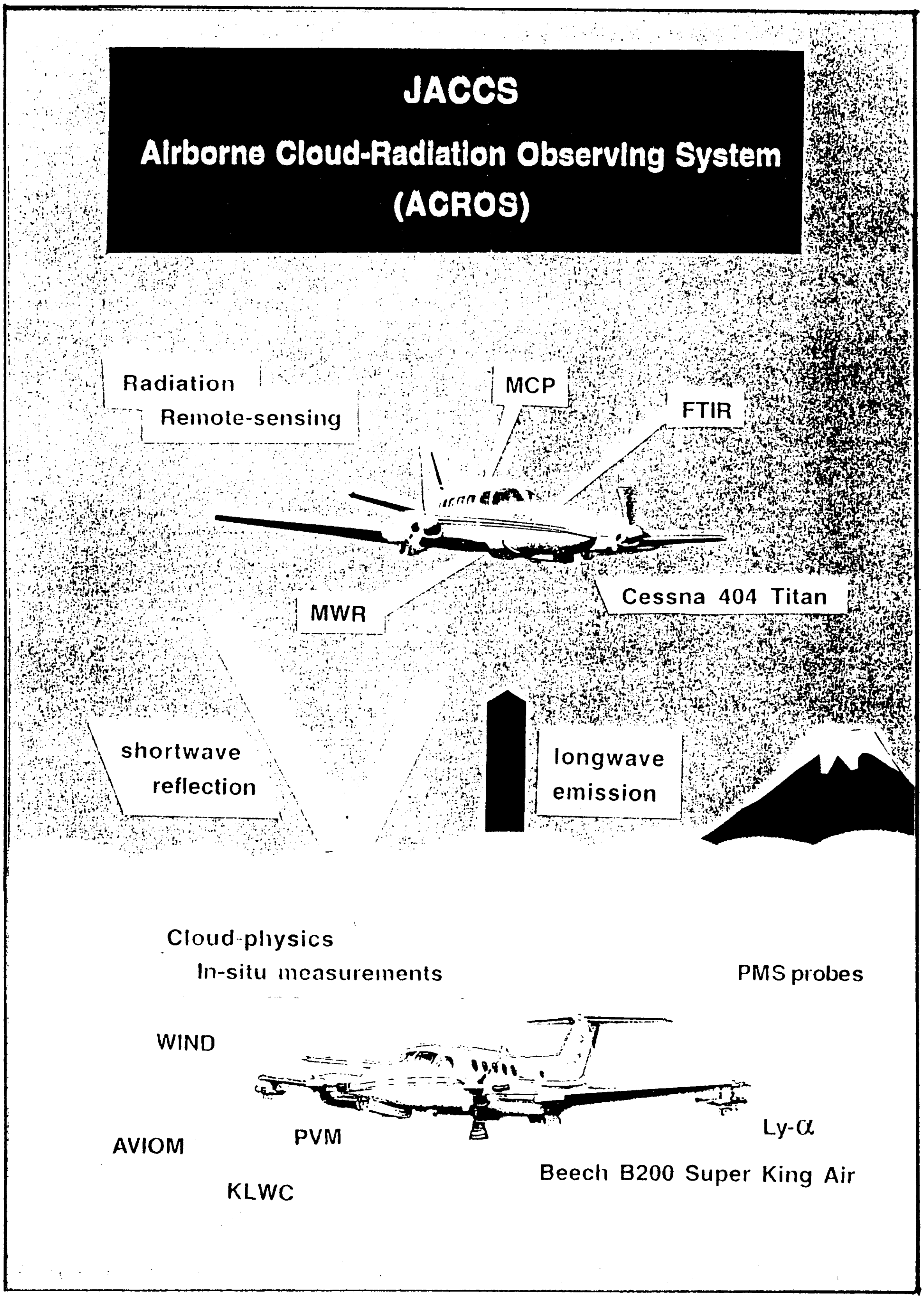


R = 0.27

T ≐ 0.67



ε ≃ 0.85

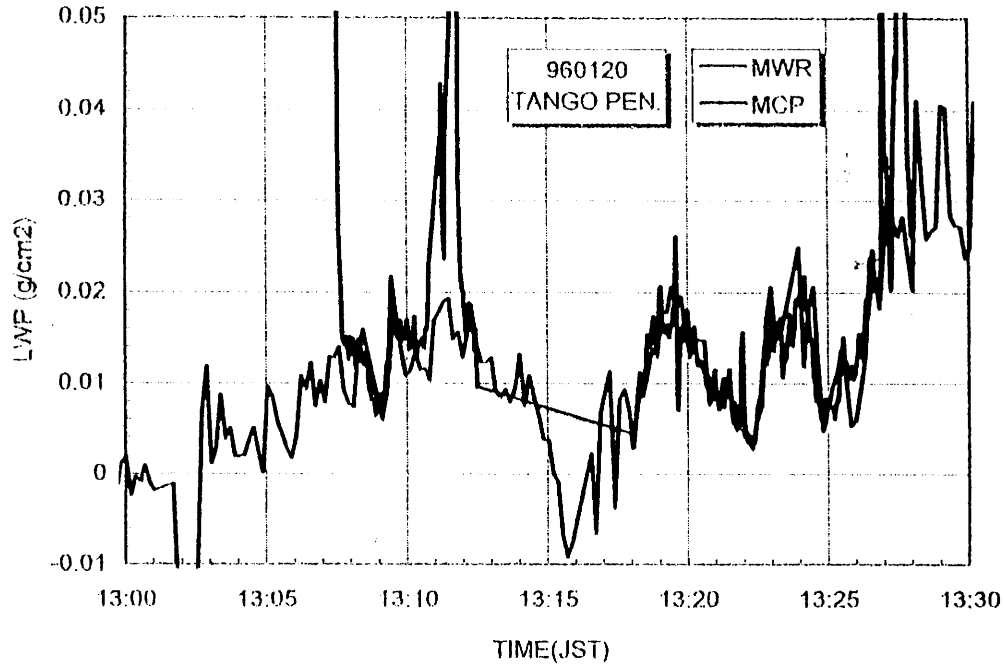


JACCS
Airborne Cloud-Radiation Observing System
(ACROS)
Radiation
Remote-sensing
MCP
FTIR
MWR
Cessna 404 Titan
shortwave
reflection
longwave
emission
Cloud-physics
In-situ measurements
PMS probes
WIND
AVIOM
PVM
KLWC
Ly-α
Beech B200 Super King Air

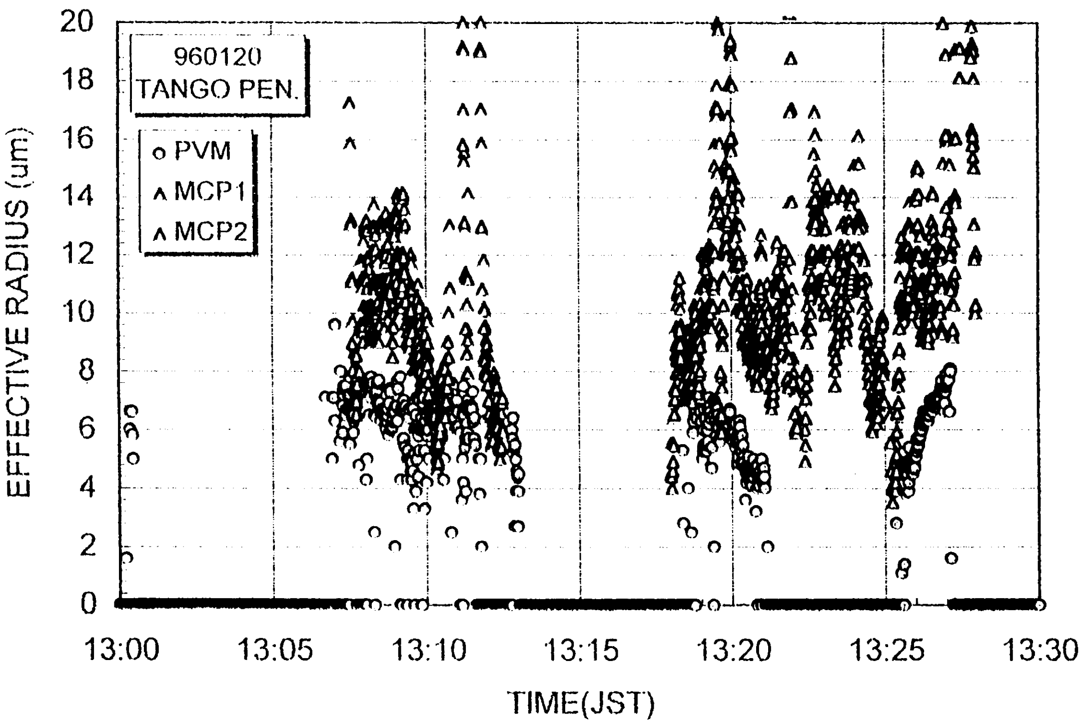
Instrumentation of ACROS for JACCS

Quantity measured	Instrument	Characteristics	Aircraft B200	Aircraft C404
(Radiation)				
Upward/downward spectral flux	Multichannel Cloud Pyranometer (MCP)	λ=421, 500, 675, 760, 862, 938, 1080, 1225, 1650nm		◎
Upward/downward solar flux	Pyranometer EKO MS-801	0.28μm< λ<2.9μm (WG305)	◎	◎
Upward/downward near-IR flux	Pyranometer EKO MS-801	0.72μm< λ<2.9μm (RG715)	◎	◎
Upward/downward infrared flux	Pyrgeometer Eppley PIR	4μm< λ<50μm	◎	◎
Nadir spectral radiance	FTIR Bomem MB155	0.71μm< λ<20μm $\Delta\nu$>1cm^{-1}		◎
Nadir infrared radiance (radiation temp)	Minarad RST-10	9.5μm< λ<11.5μm		◎
	Barnes IT-4	9.5μm< λ<11.5μm	◎	
Nadir microwave radiance	Radiometrics WVR-1100 (MWR)	23.8GHz, 31.4GHz		◎
(Cloud and aerosol microphysics)				
Cloud particle size spectrum	Airborne Video-Microscope System (AVIOM)	5μm<D<500μm	◎	
	PMS FSSP-100	2μm<D<47μm	◎	
	PMS OAP-2D2-C	25μm<D<800μm	◎	
Cloud liquid water content	PMS KLWC-5	0-5g/m^3	◎	
Effective particle radius, LWC	Gerber PVM-100A	2μm<D<70μm, 0-10g/m^3	◎	
Aerosol size spectrum	PMS PCASP-100X	0.1μm<D<3μm	◎	
(Thermodynamics)				
Total air temperature	Rosemount 102 thermometer	-50C<T<150C	◎	◎
Humidity (dew point temperature)	EG&G 137-C3 hygrometer	-65C<Td<25C	◎	◎
(water vapor absorption)	AIR Lyman-α hygrometer	λ=122nm, -80C<Td<50C	◎	
3D wind field	Rosemount 858AJ gust probe		◎	
	Rosemount 1221 pressure transducer		◎	
	INS DELCO Carousel-IV		◎	
True air speed	Rosemount 1332B pressure transducer			◎
(Others)				
Cloud morphology	Video Camera-VCR system	forward/downward looking	◎/	◎/◎
Pitch/roll/yaw angles	Vertical/directional gyro-system			◎
	INS DELCO Carousel-IV		◎	
Position latitude/longitude	GPS Trimble TNL-1000		◎	◎
Data acquisition	SEA DAS M200		◎	
	Prede DAS PDX-60CH			◎

B200: Beechcraft B200 Super King Air (Nakanihon Air Service Co., Nagoya, Japan)

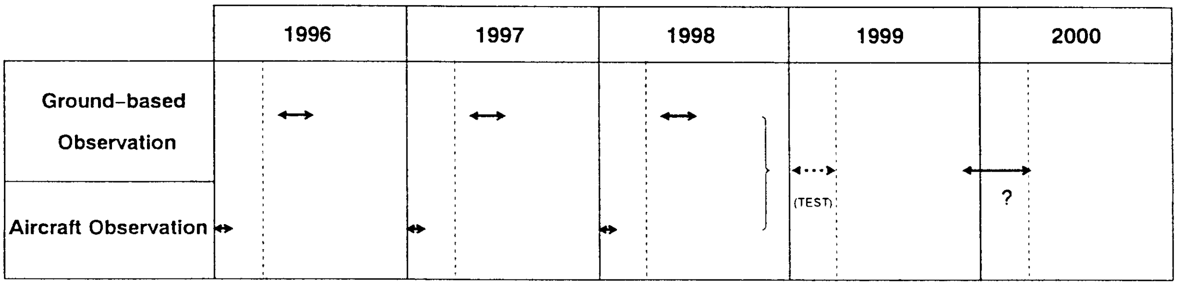


Comparison of cloud liquid water path (LWP) from nadir radiance measurements with a dual-frequency microwave radiometer (MWR) and flux reflectance measurements with MCP, on board C404 flying at the altitude of 3000m, on 20 January 1996.



Effective radii of cloud droplets from remote-sensing with MCP on board C404 (Triangles) and in-situ measurement with PVM on board B200 (circles).

Schedule of the JACCS Field Experiments



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