Airborne Cloud-Radiation Experiment for Wintertime Stratocumulus in the Japanese Cloud-Climate Study Program

S. Asano and JACCS Aircraft Observation Team[(a)]
Meteorological Research Institute
Tsukuba, Japan

Introduction

Clouds play a crucial role in radiative energy budget and water cycle in the earth-atmosphere system. In order to understand such processes as global warming and to improve assessment of climate change, it is necessary to develop climate models, which properly take into account radiation and cloud processes. In addition, it is also important to improve satellite monitoring systems for measuring the global distribution of cloudiness and cloud microphysical properties. The Japanese Cloud and Climate Study (JACCS) is a research effort focusing on these difficult problems associated with issues related to cloud-radiation interactions (Asano et al. 1994).

JACCS research activity involves aircraft observations of mid-latitude low-level and mid-level clouds in the north western-Pacific region. Major scientific objectives of the aircraft experiment are 1) to advance our understanding of the relationship between cloud micro- and macro-physical properties and radiative properties, 2) to study the cloud structures and evolution processes, and 3) to assess and improve the currently used remote sensing techniques for retrieving cloud-physical parameters for those water and mixed-phase clouds. We are especially interested in the issues of the so-called anomalous absorption of solar radiation by water clouds (e.g., Stephens and Tsay 1990).

Aircraft Cloud-Radiation Observing System

We have developed an Airborne Cloud-Radiation Observing System (ACROS) by using two aircraft equipped with various instruments for simultaneous measurements of clouds and radiation. Cessna Titan (C404) aircraft, flying over cloud layers, is used for radiation and remote-sensing measurements with a microwave radiometer (MWR), an FT-IR spectroradiometer, and a multi-channel cloud pyranometer (MCP) system developed by Asano et al. (1995a). Beechcraft Super-King-Air (B200) is used for in-situ measurements of cloud microphysics and thermodynamic properties by installing such sensors as PMS FSSP-100 and 2D-C probe, a KING hot-wire probe, a Gerber's microphysical probe (PVM; Gerber et al. 1994), Lyman-a and dew-point hygrometers on the wing-tip payrons. A few sets of wide-band pyranometers and pyrgeometers are also installed on the top and bottom of both aircraft fuselages for measuring the downward and upward solar and infrared (IR) fluxes. Specification of the ACROS instrumentation is given in Table 1. The JACCS aircraft experiment has been carried out for wintertime stratiform clouds over the sea around Japan in January of 1996 through 1998. In addition, we plan to have another aircraft experiment for stratiform water clouds in July 1998.

We have cross-checked performance of the ACROS instruments by comparing several cloud-physical parameters measured by different sensors. For example, Figure 1 shows a comparison of liquid-water-content (LWC) in-situ measured by the PVM and KING probes with those retrieved from spectral solar reflectances in the oxygen A-band (wavelength 760 nm) measured by the MCP system (Asano et al. 1995b) on board C404 for the stratocumulus cloud observed on January 22, 1997. Figure 2 compares the integrated liquid water path (LWP) of the stratocumulus layer measured by the microwave radiometer and estimated from the MCP spectral reflectances. The latter LWP was estimated from products of visible optical thicknesses and effective particle radii retrieved from the visible and near-IR reflectances measured by the MCP system (Asano et al. 1995b). These comparisons have confirmed good performance of our ACROS.

(a) JACCS Aircraft Observation Team: S. Asano (leader), A. Uchiyama, Y. Mano, Y. Takayama, M. Fukabori, M. Murakami, N. Orikasa, M. Yiyao, T. Tanaka.

Table 1. 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*, 1650*nm	◎*	◎
Upward/downward solar flux	Pyranometer EKO MS-801	0.28µm<λ<2.9 m (WG305)	◎	◎
Upward/downward near-IR flux	Pyranometer EKO MS-801	0.72µm<λ<2.9 m (RG715)	◎	◎
Upward/downward infrared flux	Pyrgeometer Eppley PIR	4µm<λ<50 m	◎	◎
Nadir spectral radiance	FTIR Bomen MB155	0.71µm<λ<20 m Δv>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]				
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			◎
	POS/DG310 ApplAnix		◎	
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).
C404: Cessna 404 Titan (Nakanihon Air Service Co., Nagoya, Japan).

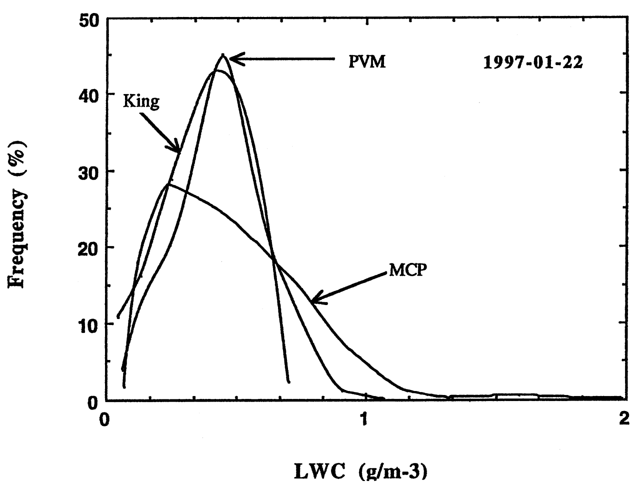

Figure 1. Frequency distributions of LWC in situ measured by Gerber probe (PVM) and KING hot-wire probe on board B200 aircraft for stratocumulus cloud observed on January 22, 1997. The MCP curve means LWC retrieved from spectral reflectance measurements by the MCP system on board C404 aircraft.

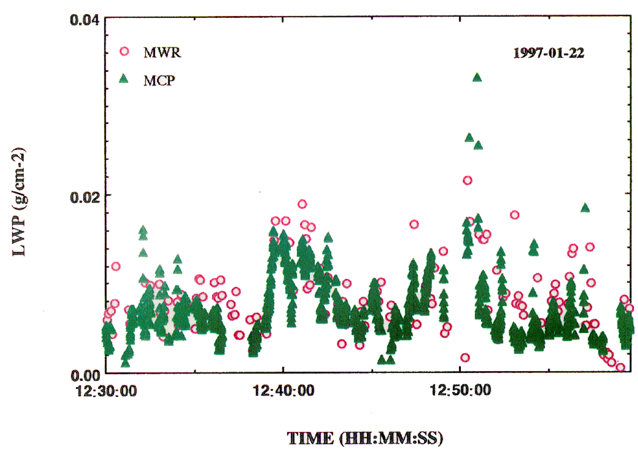

Figure 2. Comparison of the integrated LWPs measured by the microwave radiometer (MWV) and retrieved from solar spectral reflectance measurements by the MCP system on the C404 for the stratocumulus cloud on January 22, 1997. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/asano-98.pdf*.)

Aircraft Measurement of Solar Radiation Budget

Synchronized formation flights of the two aircraft, flying respectively above and below cloud layers, is our essential strategy for measuring the solar radiation budget due to cloud layers. Figure 3 shows a time series of the flight heights and the downward solar irradiances by C404 and B200 aircraft for the case of the stratocumulus cloud observed on February 2, 1998. The stratocumulus cloud horizontally extended a few hundred-kilometers wide with cloud-top temperatures around 2 °C to 4 °C at a height of 2 km. However, thickness of the cloud layer varied place by place. In the time intervals denoted by S-1 and S-3 in Figure 3, co-located flights were made for measuring radiation budgets by the cloud layer. In addition, we made a co-ordinate flight with the C404 and B200 aircraft above the cloud layer in the S-2 interval. Figure 4 demonstrates coincidence of the flight tracks by C404 and B200 aircraft for the leg S-1. The maximum time lag between the two aircraft on the flight legs was less than 1 minute.

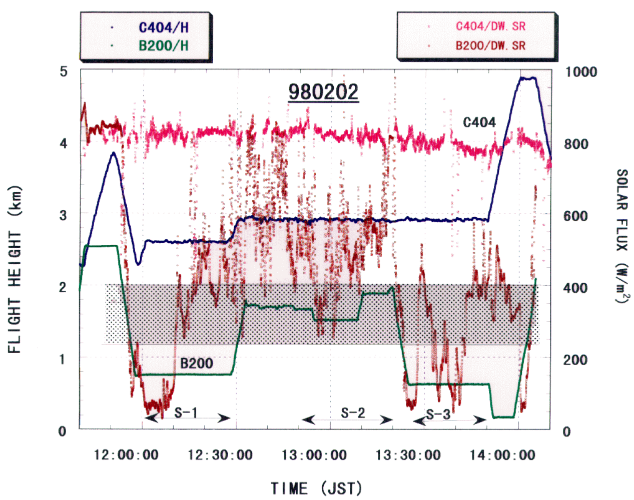

Figure 3. Time series of the flight heights (LEFT scale) and the downward solar irradiances (RIGHT scale), measured on C404 and B200 aircraft, respectively, for stratocumulus cloud layer observed on February 2, 1998. Apparent maximum region of the cloud layer is schematically shaded, but actual cloud-top and cloud-base heights varied place by place. The C404 and B200 aircraft made stacked flights in the intervals denoted by S-1, S-2 and S-3. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/asano-98.pdf*.)

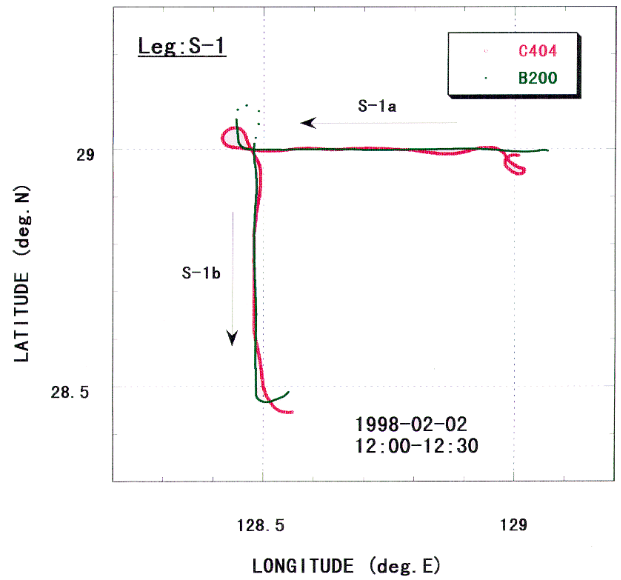

Figure 4. Horizontal flight tracks of C404 and B200 aircraft during the S-1 time interval indicated in Figure 3. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/asano-98.pdf*.)

Figure 5 shows the distribution along the S-1a north-south path of the net solar fluxes in the visible and near-IR regions measured above (C404) and below (B200) the cloud layer.

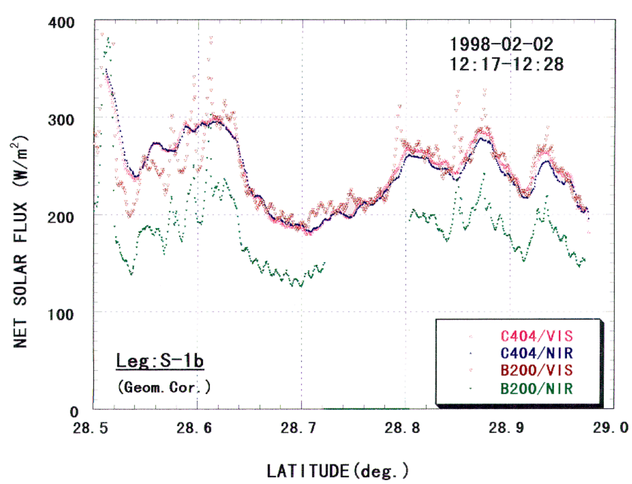

Figure 5. Distribution of the visible and near-IR net solar fluxes measured on C404 and B200, respectively, above and below the cloud layer along the north-south path of S-1a in Figure 4 for the stratocumulus cloud on February 2, 1998. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/asano-98.pdf*.)

The visible solar flux was estimated by taking differences between the total and near-IR solar fluxes measured by the total-band and near-IR-band pyranometers, respectively. There are some peaks in the net fluxes measured on B200 below the cloud layer, and these peaks were caused by concentrated penetrations of the downward solar radiation through holes and/or thinner parts of the cloud layer (Hayasaka et al. 1995). As a whole, however, the visible net fluxes measured above and below the cloud layer were almost the same within the measurement accuracy of about 10 W/m^2; this means no appreciable absorption of the visible solar radiation by the cloud layer. On the other hand, there were significant differences of 50 W/m^2 to 60 W/m^2 between the near-IR fluxes measured on C404 and B200. This difference corresponds to absorption of 6% to 7% of the total irradiance of 830 W/m^2 above the cloud layer. This amount of solar absorption seems reasonable for water clouds with the mean LWP of 50 g/m^2 measured by the MWR at the solar zenith angle 46°. Similar analysis along the other legs for thicker cloud layers have again indicated no extra solar absorption in the visible region and reasonable amounts of absorption in the near-IR region.

Conclusions

In the JACCS program we have developed the ACROS by using two aircraft equipped with various instruments for simultaneous measurements of clouds and radiation. Good performance of the ACROS has been confirmed by comparing several cloud-physical parameters measured with different sensors. By employing the ACROS, we have made careful measurements of the solar radiation budget due to cloud layers. Preliminary analysis suggests that water clouds absorb no extra solar radiation in the visible region and reasonable amounts of solar radiation in the near-IR region. So, there was no evidence of the so-called anomalous solar absorption in our particular case.

Acknowledgments

JACCS is supported by the Science and Technology Agency of the Japanese government. We thank Nakanihon Air Service Co., LTD. and Science Engineering Associates for their help with the JACCS Aircraft experiment.

References

Asano, S., and JACCS/MRI Research Group, 1994: Japanese Cloud Climate Study (JACCS): Research plan and preliminary results. *Preprint of the 8th Conf. Atmos. Radiation* (January 23-28, 1994, Nashville, Tennessee), Am. Meteor. Soc., 282-284.

Asano, S., M. Shiobara, Y. Nakanishi, and Y. Miyake, 1995a: A multichannel cloud pyranometer system for air-borne measurement of the solar spectral reflectance by clouds. *J. Amos. Oceanic Tech*., **12**, 479-487.

Asano, S., M. Shiobara, and A. Uchiyama, 1995b: Estimation of cloud physical parameters from airborne solar spectral reflectance measurements for stratocumulus clouds. *J. Atmos. Sci*., **52**, 3556-3576.

Gerber, H., B. G. Arends, and A. S. Ackerman, 1994: New microphysics sensor for aircraft use. *Atmos. Research,* **31**, 235-252.

Hayasaka, T., N. Kikuchi, and M. Tanaka, 1995: Absorption of solar radiation by stratocumulus clouds: Aircraft measurements and theoretical calculations. *J. Appl. Meteor*., **34**, 1047-1055.

Stephens, G. L., and S.-C. Tsay, 1990: On the cloud absorption anomaly. *Quart. Roy. Meteor. Soc.*, **116**, 671-704.