―報告―
Reports

Antarctic Middle Atmosphere Project at Syowa Station

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昭和基地における南極 MAP 計画

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要旨：1982年から1985年の間，国際的に実施される中層大気観測計画 (MAP) の一環として，南極の昭和基地においても総合的な極域中層大気観測が実施される．中層大気の観測方法として，地上，飛行機，衛星を用いてのリモートセンシングおよび飛行機，気球，ロケットを用いての直接観測を行う．地上からのリモートセンシングによる主な観測装置は，レーザレーダー，VHF ドップラーレーダー，赤外分光，ドブソン法分光器などである．この論文では，これらプロジェクトの概要を示す．

Abstract: Coordinated observations of the polar middle atmosphere are being carried out at Syowa Station in Antarctica as part of the Middle Atmosphere Program (MAP) for 1982–1985. The middle atmosphere is measured by a combination of remote sensing techniques from the ground, aircraft and spacecraft and *in situ* measurements by aircraft, balloon and sounding rocket. The main ground-based remote sensing facilities are laser radar, VHF doppler radar, infrared spectrometer and Dobson spectrophotometer. This paper gives an outline of this project.

1. Introduction

Coordinated observations of the middle atmosphere are being carried out at ground-based facilities of Syowa Station in Antarctica, and from aircraft, balloons, sounding rockets and spacecraft. The Middle Atmosphere Program (MAP) is an international cooperative enterprise scheduled for 1982–1985. Its main aim is to obtain a comprehensive understanding of the middle atmosphere which is defined between the tropopause and the lower thermosphere (approximately 10–120 km). This altitude range is the least explored and understood part of the earth's atmosphere due to lack of proper techniques available for its exploration. Particularly our knowledge about the middle atmosphere in the southern polar region is most deficient. Therefore, the Geodesy Council of Japan presented a recommendation to the Ministry of Education, Science and Culture that coordinated observations of the middle atmosphere in Antarctica should be carried out as one of the major national projects for the MAP. Under these circumstances the National Institute of Polar Research has established the Antarctic Middle Atmosphere Project for 1982–1985. This paper gives the outline of this project and its progress at Syowa Station.

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2. Scientific Aims and Facilities

Main scientific aims of the MAP project at Syowa Station are as follows:

(i) Study of dynamics, structure and composition of the polar middle atmosphere,

(ii) Study of roles of auroral energy on energetics, dynamics and composition of the polar middle atmosphere,

(iii) Study of atmospheric pollution,

(iv) Study of the sun-weather relationship.

The fourth subject will be studied by analyzing ice core samples taken from a 500 m depth obtained at Mizuho Station. Other subjects will be studied by using various kinds of data obtained by the following facilities of Syowa Station.

(1) Ground-based facilities: Dobson spectrophotometer, laser radar (ruby laser, dye laser), infrared spectrometer for minor constituent measurement, visible spectrometer for NO_2 and NO_3 measurement, VHF doppler radar (aurora radar mode, meteor radar mode), all-sky camera, all-sky TV camera, photometer (meridian scanning, fixed-direction), riometer (single beam, multi-beams), magnetometer (fluxgate, search coil), ionosonde, ELF-VLF receiver, HF receiver.

(2) Aircraft: Aerosol counter, radiometer, air sampling.

(3) Balloon and sonde: Rawin sonde (temperature, wind), ozone sonde, radiation sonde, visible spectrometer for NO_2 measurement, auroral X-ray detector, electric field detector, ionization rate counter.

(4) Rocket and rocketsonde: Particle detector, electric field detector, magnetometer, plasma wave receiver (ELF, VLF, HF), electron density and temperature probes, rocketsonde (temperature, wind).

(5) Satellite data acquisition:

EXOS-C: Limb scanning infrared photometer for ozone measurement, limb scanning ultraviolet photometer for aerosol and ozone measurement, ultraviolet spectrometer for ozone measurement, infrared scanning radiometer for minor constituent measurement, plasma sounder, electron density and temperature probes, high energy particle detector, low energy particle detector.

NOAA-7, -8: Scanning radiometer (AVHRR), TOVS, particle detector.

ISIS-1, -2: Topside sounder, VLF receiver.

3. Subjects of Experiments and Measurements Techniques

Major subjects and measurement techniques of the MAP project at Syowa Station are as follows.

3.1. Ozone

The middle atmosphere temperature profile is determined by the balance between energy supply due to absorption of the solar ultraviolet radiation by O_2 and O_3 and infrared cooling, mainly by carbon dioxide. Therefore, ozone plays a dominant role in the middle atmosphere. Both total ozone and the vertical profile of ozone are measured by a combination of ground-based remote sensing by Dobson spectrophotometer and remote sensing from the EXOS-C and NOAA-7, -8 satellites. The Dobson spectrometer set up at Syowa Station can measure the total ozone content throughout the year by measuring absorption lines in the sunlight and moonlight. Ozone sondes are also used for *in situ* measurements of ozone.

3.2. Aerosole

It is generally believed that stratospheric aerosols are supplied by volcanic injection events, and are transported toward high latitudes by a general circulation of the atmosphere. The aerosol content of the stratosphere is an important factor of stratospheric warming and cooling at the earth's surface. Therefore, the understanding of relationships between the aerosol content in the middle atmosphere and the global climate change is one of the most important subjects of the MAP. The radiative effect of stratospheric aerosols depends on altitude, concentration and size distribution. The effect on surface insolation also depends on these factors.

The vertical profile of the aerosol content is measured by a laser radar system with ruby laser which shoots laser pulses of 694.3 nm (fundamental) and 347.1 nm (second harmonic). The power of these laser pulses is 1J and 0.25J, respectively.

The density of aerosols is also measured by the limb absorption experiment on EXOS-C. *In situ* measurements of aerosols are carried out by balloons and aircraft.

3.3. Minor constituents

Measurements of minor constituents is important for understanding the structure and behavior of the ozone layer in which ozone is lost largely by reaction with minor constituents as odd-nitrogen and odd-hydrogen compounds. The measurement of minor constituents is also necessary for studying pollution problems. The Antarctic region is the most suitable place for monitoring the global diffusion of the atmospheric pollution since it is located far from the pollution sources in the northern industrial areas. The column densities of N_2O, HNO_3, CO, CH_4, $CFCl_3$, and CF_2Cl_2 are measured by ground-based remote sensing technique using an infrared spectrometer. The vertical profiles of these minor constituents are also measured by an infrared spectrometer on board EXOS-C.

The column densities of NO_2 and NO_3 are measured by monitoring visible absorption lines on the ground. Sampling of minor constituents is carried out by aircraft.

3.4. Thermospheric winds

Electric fields generated by an interaction between the solar wind and the magnetosphere penetrate into the polar ionosphere. The thermospheric winds are driven by Lorentz force associated with these intense electric fields. It is well-known that in the E region of the polar ionosphere auroral electrojet currents are driven by these electric fields. The Joule heating due to the electrojet currents together with heating by precipitating auroral particles is an important energy source for thermospheric dynamics.

The motions of ionized and neutral atmosphere in the 80–120 km altitude range are monitored by a VHF doppler radar. This radar has functions of both the auroral radar and meteor radar. The frequency and power of its transmitter are 50 MHz and 15 kW, respectively. The radar has two beams which are aligned along the geomagnetic meridian and 30 westward from it. The wind speed and direction are estimated by combining doppler shifts measured by these two beams.

3.5. Gravity wave and tide

It is believed that gravity waves and tides play an essential role in the general circulation of the middle atmosphere. The momentum in the lower stratosphere is transported upward by these waves. Therefore, measurements of gravity waves and tides are important for the understanding of dynamics of the middle atmosphere.

Traveling ionosheric disturbances (TIDs) caused by the passage of internal atmospheric gravity waves are often observed to propagate away from high latitude regions during magnetic disturbances. Therefore, one possible source of TIDs is gravity waves generated through Joule heating or Lorentz force associated with the auroral electrojet.

The measurements of gravity waves and tides are carried out by a combination of ground-based remote sensing (laser radar, meteor radar) and *in situ* measurements by rocketsondes. The laser radar with a tunable dye laser measures the atmospheric sodium layer in the 80–100 km region and the vertical profile of air density in the 30–80 km region. The meteor radar measures motions of atmospheric air in the 80–100 km region. The MT-135JA-type rocketsondes measure winds and temperatures in the 20–60 km region.

3.6. Sudden stratospheric warmings

Sudden stratospheric warmings which occur irregularly in winter are characterized by anomalous amplification of planetary wave in the polar stratosphere and distortion of the normal cyclonic polar vortex. The zonal mean temperature increases at high latitudes and decreases at low latitudes. Associated with such heat transport to the polar stratosphere, mesospheric cooling occurs at high latitudes.

Sudden stratospheric warming events are monitored by *in situ* measurements of rawin sondes and ozonesondes. The poleward motion of the warming region is monitored by remote sensing of the total ozone content from the EXOS-C and NOAA-7, -8 satellites. The measurements by the laser radar and the VHF doppler radar give further information on these events.

3.7. Solar and atmospheric radiation

The measurements of downward and upward fluxes of solar radiation and infrared radiation at different altitudes of the stratosphere are necessary for understanding the middle atmosphere photochemistry and dynamics. The measurement of surface insolation is also necessary for studying energetics of the middle atmosphere. The reflection coefficient at the surface in Antarctica is high since the surface is covered with ice and snow. The infrared radiation is measured from sondes, aircraft and the EXOS-C and NOAA-7, -8 satellites. The solar visible and ultraviolet radiations are measured from aircraft and at the ground.

3.8. Auroral phenomena

In the polar region energy sources associated with auroral phenomena play an essential role in energetics and dynamics of the middle atmosphere. Joule heating by auroral electrojet and heating by precipitating particles are main energy sources of the lower thermosphere. Precipitating particles and auroral X-rays also cause appreciable changes in composition of minor constituents.

The intensities of auroras are measured by a meridian-scanning photometer and a zenith photometer. The spatial distribution and motion of auroras are measured by all-sky camera and low-light-level TV camera with a fish-eye lense. Precipitating electrons in the daytime and in the overcast night are monitored by riometers. The spatial distribution and motion of precipitating electrons are measured by a multi-beam riometer. Auroral electrojet currents are monitored by magnetometers set up at Syowa and Mizuho Stations.

Simultaneous measurements of auroral precipitating electrons, magnetic and electric field variations and electromagnetic waves are carried out by the S-310JA-type sounding rockets. Auroral X-rays and electric fields are measured from balloons.

4. Operation at Syowa Station

4.1. 1982 campaign carried out by JARE-23

The 23rd Japanese Antarctic Research Expedition (JARE-23) party constructed a VHF doppler radar with auroral radar mode and meteor radar mode and balloon launching facilities at Syowa Station in January 1982. They also improved the Dobson spectrophotometer to measure the total ozone content and the vertical profile of ozone throughout the year. Table 1 summarizes the MAP activities at Syowa Station in 1982. The main experiments carried out by JARE-23 are as follows:

(i) Comprehensive observation of ozone by means of a combination of remote sensing techniques from the ground (Dobson spectrophotometer) and from the NOAA-6 and -7 satellites and *in situ* measurements by ozone sonders,

(ii) Observation of dynamics of the lower thermosphere by the VHF doppler radar,

(iii) Telemetry reception of remote-sensing data measured by the NOAA-6, -7 and ISIS-1, -2 spacecraft,

(iv) Observation of energy sources associated with auroral phenomena by using ground-based facilities (all-sky TV camera, photometers, riometer and magnetometer) and auroral X-ray and electric field detectors on board balloons.

4.2. 1983 campaign carried out by JARE-24

JARE-24 party set up three kinds of ground-based remote-sensing facilities, that is, a laser radar system using ruby laser, an infrared spectrometer, and a visible spectrometer. Table 1 summarizes the MAP activities at Syowa Station in 1983. The main experiments carried out by JARE-24 are as follows:

(i) Observation of aerosols by the laser radar system and aerosol counters on board aircraft and balloons together with air sampling on aircraft,

(ii) Observation of minor constituents and air pollution ($CFCl_3$, CF_2Cl_2, HNO_3, NO_2, CO, CH_4) by the infrared spectrometer,

(iii) Observation of NO_2 and NO_3 by visible spectrometers on the ground and on balloons,

(iv) Observation of dynamics of the lower thermosphere by the VHF doppler

Table 1. Facilities for the Antarctic Middle Atmosphere Project at Syowa Station in 1982 and 1983. Open circles denote the facilities which were operated only in 1982, while asterisks denote the facilities which were operated only in 1983.

	Observation item	Ground	Aircraft	Balloon, sonde	Spacecraft
Composition	Total ozone content	Dobson spectrophotometer			NOAA-6, -7 (TOVS)
	Ozone vertical profile			Ozone sonde	
	Aerosol	Laser radar (ruby laser)*	Aerosol counter* Air sampling*	Aerosol sonde*	
	Minor constituents	Infrared spectrometer* Visible spectrometer*	Air sampling*	NO_2 spectrometer	
	Water vapor		Hydrometer*	Water vapor sonde*	
	Ionization			Ionization rate counter	
	Electron density	Ionosonde			ISIS-1, -2 (sounder)
Motion	Ionized atmosphere (wind, wave)	VHF doppler radar			
	Neutral atmosphere (wind, wave)	Meteor radar		Rawin sonde	
	Neutral atmosphere (temperature, pressure, density)			Rawin sonde	NOAA-6, -7 (TOVS)
Radiation	Solar radiation (visible, ultraviolet)	Solar radiometer	Solar radiometer*		
	Atmospheric radiation (infrared)		Radiometer*	Radiometer sonde	NOAA-6, -7 (TOVS)
Auroral energy	Auroral motion	All-sky camera All-sky TV camera°			
	Auroral intensity	Meridian scanning photometer Fixed-direction photometer			
	Precipitating particle	Riometer		Auroral X-ray counter	NOAA-6, -7 (particle detector)
	Auroral electrojet	Magnetometer			
	Electric field	VHF doppler radar		Electric field detector	
	Electromagnetic wave				ISIS-1, -2 (VLF receiver)

radar,

(v) Telemetry reception of remote-sensing data measured on the NOAA-6, -7 and ISIS-1, -2 satellites,

(vi) Observation of energy sources associated with auroral pnenomena.

4.3. 1984 campaign to be carried out by JARE-25

JARE-25 party constructed a new radar tracking and telemetry system in January 1984 for the rocket experiment. Three S-310JA-type sounding rockets will be launched at Syowa Station in the period of April–June 1984 for measuring auroral phenomena. The MAP project in 1984 is summarized in Table 2. JARE-25 will carry out the following experiments:

(i) Rocket observations of precipitating electrons, auroral visible image, electron density and temperature, and magnetic field,

(ii) Telemetry reception of remote-sensing data measured by the EXOS-C and NOAA-7, -8 satellites,

(iii) Observation of auroral images by monochromatic CCD camera and all-sky SIT camera,

(iv) Observation of aerosols by aerosol sondes and aerosol counter on board aircraft,

(v) Observation of dynamics of the lower thermosphere by the VHF doppler radar.

4.4. 1985 campaign to be carried out by JARE-25

This year is the last year of the MAP period. Therefore, comprehensive observations of the middle atmosphere will be carried out at ground-based facilities, and from balloons, rockets and satellites. Table 2 summarizes the items of observations in 1985, while Fig. 1 is a schematic diagram of the observation facilities at Syowa Station. The main experiments are as follows:

(i) Observation of precipitating electrons, electron density and temperature, magnetic and electric fields and plasma waves in the 60–220 km altitude region by the S-310JA-type rockets,

(ii) Observation of wind and temperature up to 60 km by MT-135JA-type rocketsondes,

(iii) Observation of the sodium layer in the 80–100 km region by the laser radar system with tunable dye laser,

(iv) Observation of aerosols by the ruby laser radar system on the ground and balloon-borne aerosol counters,

(v) Observations of ozone by the Dobson spectrophotometer and ozonesondes,

(vi) Telemetry reception of remote-sensing data measured on board the EXOS-C, ISIS-1, -2 and NOAA-7, -8 satellites,

(vii) Observation of precipitating electrons by multi-beam riometer system,

(viii) Observation of dynamics of the lower thermosphere by the VHF doppler radar,

(ix) Observation of vertical profiles of air density by the laser radar system.

Table 2. Facilities for the Antarctic Middle Atmosphere Project at Syowa Station in 1984 and 1985. Open circles denote the facilities which are operated only in 1984, while asterisks denote the facilities which are operated only in 1985.

	Observation item	Ground	Aircraft	Balloon, sonde	Rocket	Spacecraft
Composition	Total ozone content	Dobson spectrophotometer				NOAA-7, -8, (TOVS) EXOS-C (UV spectrometer)
	Ozone vertical profile			Ozone sonde		EXOS-C (lim scanning infrared photometer)
	Aerosol	Laser radar (ruby laser)	Aerosol counter° Air sampling°	Aerosol sonde		EXOS-C (lim scanning ultraviolet photometer)
	Minor constituents	Infrared spectrometer°	Air sampling°			EXOS-C (infrared spectrometer)
	Water vapor	Laser radar (ruby laser)*	Hydrometer°	Water vapor sonde		EXOS-C (infrared spectrometer)
	Electron density	Ionosonde			S310 (electron density)	ISIS-1, -2 (sounder) EXOS-C (sounder)
	Sodium layer	Laser radar (dye laser)*				
Motion	Ionized atmosphere (wind, wave)	VHF doppler radar				
	Neutral atmosphere (wind, wave)	Meteor radar Laser radar (dye laser)*		Rawin sonde	MT135 (wind)*	
	Neutral atmosphere (temperature, pressure, density)	Laser radar (ruby laser)*		Rawin sonde	MT135 (temperature)*	NOAA-7, -8 (TOVS)
Radiation	Solar radiation (visible, ultraviolet)	Solar radiometer	Solar radiometer°			
	Atmospheric radiation (infrared)		Radiometer°	Radiometer sonde		NOAA-7, -8 (TOVS)
Auroral energy	Auroral motion	All-sky camera All-sky TV camera			S310 (TV camera)°	
	Auroral intensity	Meridian scanning photometer Fixed-direction photometer			S310 (photometer)°	
	Precipitating particle	Single-beam riometer Multi-beam riometer*		Auroral X-ray counter*	S310 (particle detector)	EXOS-C (particle detector)
	Auroral electrojet	Magnetometer			S310 (magnetometer)	NOAA-7, -8 (particle detector)
	Electric field	VHF doppler radar			S310 (electric field detector)*	
	Electromagnetic wave	ELF, VLF, HF receivers		ELF-VLF receiver*	S310 (VLF, HF receivers)*	EXOS-C (plasma wave detector) ISIS-1, -2 (VLF receiver)

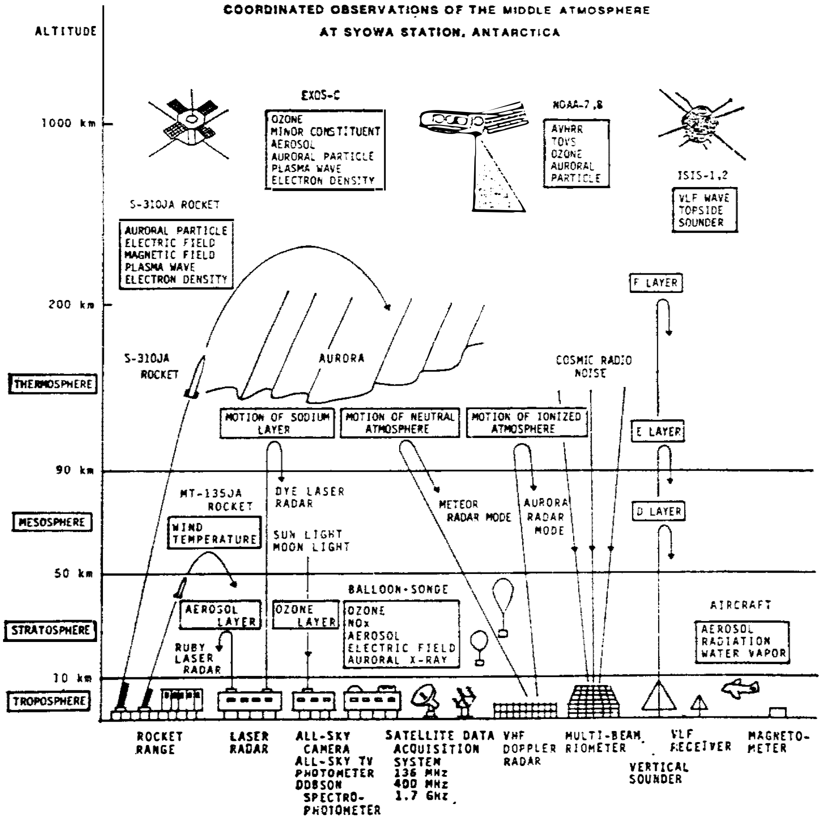

Fig. 1. Schematic diagram of the facilities to be operated at Syowa Station in 1985 for the Antarctic Middle Atmosphere Project.

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