Japanese satellite programs related to the tropospheric vertical soundings

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1. Status and plans

Appendix will serve as a terse summary of the status and plans of Japanese space programs. The atmospheric sounding sensors are involved in ADEOS (Advanced Earth Observing Satellite) and following satellites. The questions for details should be addressed to Mr. Moriyama, the Earth Observation Center/NASDA. In this paper we briefly describe the tropospheric sounding sensors proposed in Japanese Earth Observation System from 1998.

2. Tropospheric sounding sensors proposed for Japanese Polar Orbiting Satellite

Five sensors have been proposed for tropospheric sounding in JPOP(Japanese Polar Orbiting Satellite). They are AMSR(Advanced Microwave scanning Radiometer), LIDAR(LIght Detection And Ranging), TERSE(Tunable Etalon Remote Sounder for the Earth), FPITS(Fabry-Perot Inverse Transform Spectrometer) and ISTG(Interferometric Spectrometer for Temperature and Greenhouse gases). AMSR is a microwave sensor to measure the water vapor, cloud water, atmospheric and surface temperature and has 6 channels between 6-90 GHz. LIDAR measures the vertical profiles of water vapor and other composition, and surface level of cloud, sea, ice and snow by the technique of laser radar. FPITS is a new type of spectrometer using a scanning Fabry-Perot interferometer to obtain a high resolution spectra of the atmosphere. The wavenumber range which can be covered by one detector of this instrument is narrower than that of the Fourier Transform Spectrometer(FTS), however, the distance of moving mirror is one order smaller than that of FTS so that the size of the instrument can be very small to be suitable to the space borne sounder(Aoki, 1990). ISTG is the post version of IMG(Interferometric Measurement of Greenhouse Gases) which is a FTS to be boarded on ADEOS in 1995. Further details of these four instruments have not been given yet.

TERSE is an instrument for sounding the tropospheric trace gases such as CO_2, CH_4, N_2O, CO, H_2O and HDO by observing reflected solar radiation in the wavelength range between $1.2-2.4\mu m$ and the details have already been given(Aoki, 1989a,b): Fig.1

shows the schematic diagram of this instrument, where FP is the tunable etalon, F the etalon tuned narrow band pass filter and D the detector. The atmospheric transmission spectra for CO_2 measurement, for example, is shown in Fig.2, where the spectrum in the lowest panel is the transmission spectrum of the total atmospheric gases, and the second and third panels are those of H_2O and CO_2 in the US standard atmosphere. The panel denoted by 'FILTER' is the spectrum of narrow band pass filter and those denoted by 'FP1' are the transmission spectra of tunable etalon for different values of etalon plates spacing, where the reflectance of the etalon plate has been assumed to be 0.9 and the absorption by etalon has been neglected.

We obtain the density vertical profile by simultaneously using observed radiances for various etalon spacings. The radiance to be measured is written in the following equation:

$$R_i(\delta_i) = \int_{\nu_1}^{\nu_2} d\nu \phi_{FP}(\nu, \delta_i)\phi_B(\nu) r_s(\nu)[R_{refl}(\nu) + R_{path}(\nu)], \tag{1}$$

where δ_i is the etalon spacing at the i-th observation, ν_1 and ν_2 are the lower and upper limits of the wavenumber, respectively, ϕ_{FP} is the transmission function of the tunable etalon, ϕ_B is the transmission function of the narrow band pass filter, R_{refl} is the component of the radiance reflected at the surface and R_{path} is that scattered by the atmosphere. By expanding this equation around an initial value we obtain

$$R_i(\delta_i) = R_i^\circ(\delta_i) + \sum_{m=1}^{M} \frac{\partial R_i}{\partial x_m} x_m, \tag{2}$$

$$X = [\Delta\rho_1, \Delta\rho_2, ...\Delta\rho_N, \Delta T_1, \Delta T_2, ...\Delta T_N, \Delta P_s, ..], \tag{3}$$

$$y_i \equiv R_{i,obs} - R_i^\circ = \sum_m K_{im} x_m, \tag{4}$$

$$K_{im} = \frac{\partial R_i}{\partial x_m}, \tag{5}$$

where R° is the calculated radiance under the condition of the initial guess. $\Delta\rho_i$ and ΔT_i are the deviation of the density and temperature from the initial guesses at the i-th layer, respectively and ΔP_s is that of the surface pressure.

The unknown parameters are determined by the method of Rodgers(1976) as

$$X_{(n+1)} = (S_x^{-1} + K_{(n)}{}^t S_\epsilon^{-1} K_{(n)})^{-1} K_{(n)}{}^t S_\epsilon^{-1}[Y - Y_{(n)} + K_{(n)} X_{(n)}], \tag{6}$$

where $X_{(n)}$ is the X at the n-th step of the iteration, S_x is the covariance matrix of X, $K_{(n)}$ is the K appeared in (5) at the n-th step and S_ϵ is the covariance matrix of the measurement error. Fig.3 is an example of the retrieved profile(thin solid line) for calculated observed radiances in which 2 K of constant temperature error has been introduced, being compared with the true one(thick solid line) and the initial value(dashed line). The retrieval error is shown on the left hand side of the figure. It can be seen that in the lower troposphere the error is about a few percent.

The advantage of using the absorption of the reflected solar radiation compared to the emission method for sounding the vertical profile of the tropospheric gases is shown in Table 1. In this table $R^{\odot}$ is the solar radiation at the top of the atmosphere, $\tau(z)$ is the transmittance from the top to the height z, μ is the cosine of zenith angle of the sun, which is assumed here to be equal to the reflection angle, k is the absorption coefficient, B is the Planck function, T_b is the brightness temperature, T_s is the surface skin temperature and $\tilde{T}$ is the mean temperature between $z = 0 \sim z$. Here, for simplicity, we considered the case where the incident and reflection angles are the same and path radiance is neglected.

Since for sounding the lower troposphere we must use the wavelength where the transmittance is large in both the absorption and emission method, we assume the value of k is the same order in both method. In this case it will be found that the information content of emission method is the order of less than 1/10 of that of the absorption method. In other word the emission method is less sensitive to the density change; In an extreme case of constant temperature we have no information on the density profile.

In addition, it is shown in the table that the emission method strongly relies on the temperature profile and the error of the temperature profile directly affects the retrieved density profiles while the absorption method only slightly depends on the temperature through the value of k.

3. References

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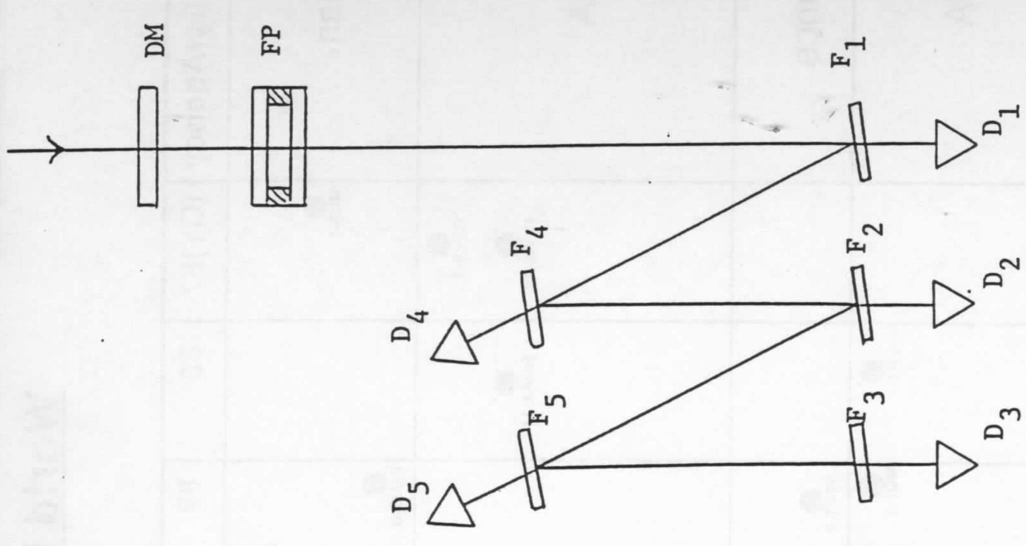

Fig.1. Schematic diagram of the TERSE(Tunable Etalon Remote Sounder for the earth).

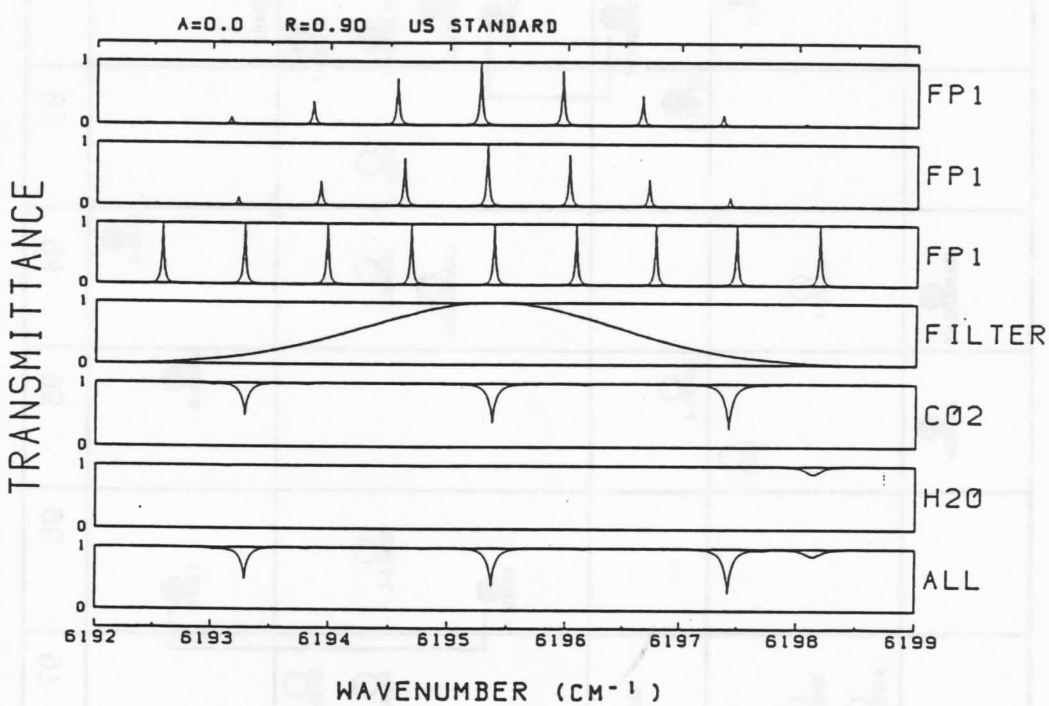

Fig.2. Transmittance spectra of the column atmosphere(lower panel), H_2O and CO_2, band pass filter('FILTER'), and tunable etalon(upper three columns).

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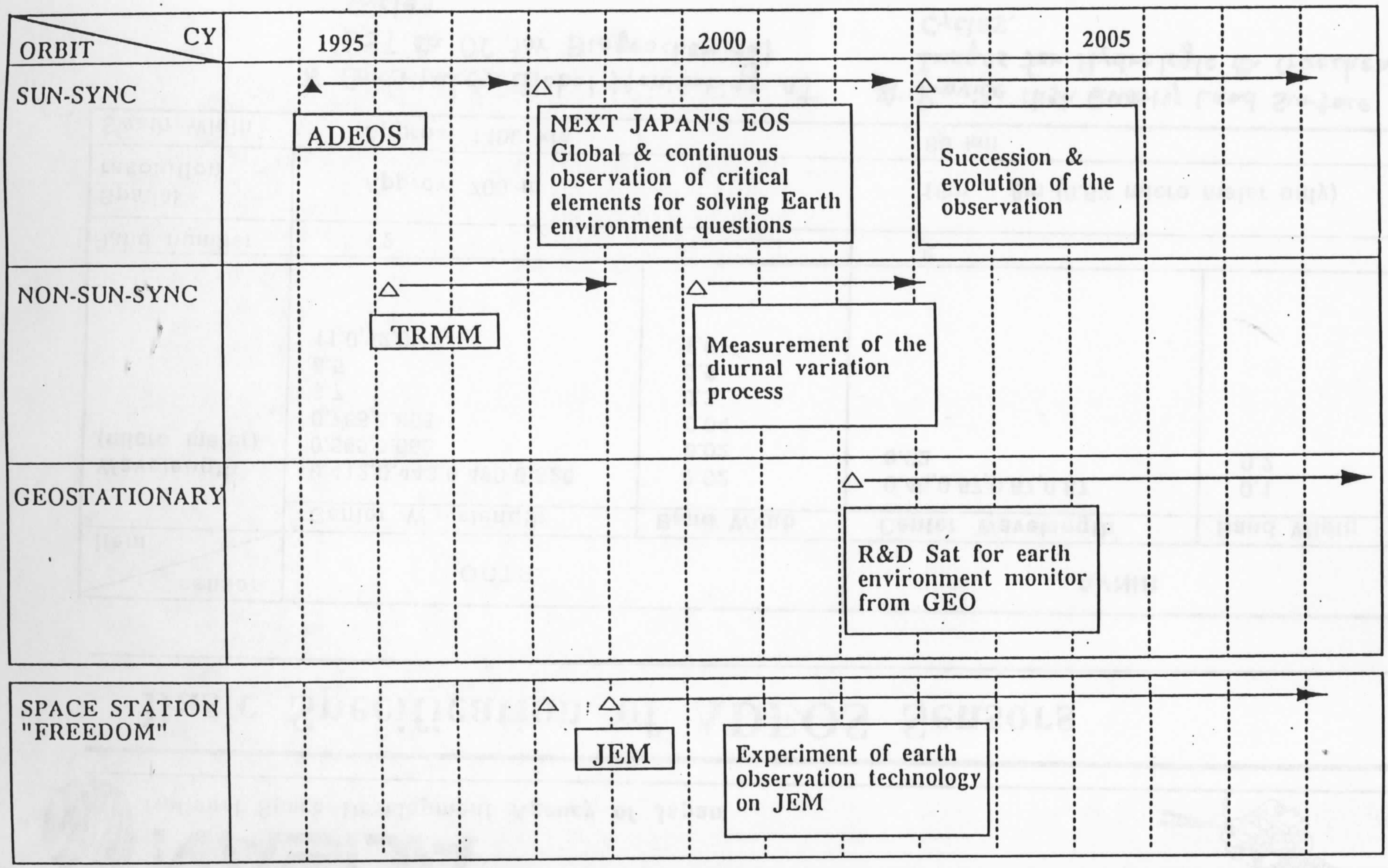
World Earth Observation Satellite Programs

Country/Agency	(CY)87	88	89	90	91	92	93	94	95	96	97	98-
Japan	● MOS-1		● GMS-4 ● EXOS-D	● MOS-1b	◍ SOLAR-A	◍ JERS-1 ◍ GEOTAIL		◍ GMS-5	◍ ADEOS	◍ TRMM		○ JPOP
USA	● GOES-7 ● NOAA-10	● NOAA-11			◍ NOAA-D ◍ UARS	◍ GOES-I ◍ GOES-J ◍ SeaWIFS ◍ NOAA-I ◍ LANDSAT-6 ◍ TOPEX	○ NOAA-J	○ NOAA-K ○ LANDSAT-7		○ NOAA-L ◍ TRMM	○ GOES-K ○ GOES-L ○ NOAA-M	○ GOES-M ○ IPOMS ◍ EOS-a
France			● SPOT-2			◍ POSEIDON	◍ SPOT-3		○ SPOT-4		○ GLOBSAT	○ BEST
ESA		● P2	◍ MOP-1 ◍ MOP-2		◍ EERS-1	◍ MOP-3		○ EERS-2	○ MSG		○ EPOP/M1 ○ ARISTOTELES	
Others		● INSAT-1-C ● IRS	○ INSAT-1-D		◍ INSAT-2			◍ RADARSAT	◍ ATMOS			

● Operational ◍ Under development ○ Planned/Considered

Earth Observation Center

CONCEPTION OF JAPAN'S EARTH OBSERVING SCENARIO



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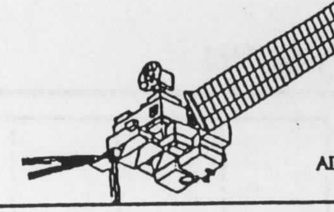

Basic Specification of ADEOS Sensors

item \ sensor	OCTS		AVNIR	
	Center Wavelength	Band Width	Center Wavelength	Band Width
Wavelength (micro meter)	0.412,0.443,0.490,0.520 0.565,0.665 0.765,0.865 3.7 8.5 11.0,12.0	0.02 0.02 0.04 0.3 0.5 1.0	0.45,0.57,0.67,0.87 0.62	0.1 0.2
Band number	12		5	
Spatial resolution	Approx. 700 m		16m , 8m (0.62 micro meter only)	
Swath Width	Approx. 1400 km		80 km	

★ Contributes Global Monitoring of SST & OC for Biogeochemical Cycles.

★ Provide High Quarity Land Surface Images for Hydrologic & Geochemical Cycles.

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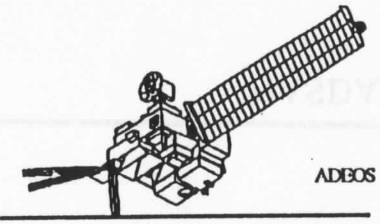

Specification of ADEOS A.O. sensors

Sensors	Agency	Major Specification	Objectives
NSCAT	NASA/JPL (USA)	Swath width : 1200km Frequency : 13.995GHz Wind speed accuracy : +-2m/s or 10% Wind direction accuracy : +-20 degree IFOV : 25 X 25 Km Data rate : 3.2 Kbps	Measurement of surface wind speed and direction over the global oceans.
TOMS	NASA/GSFC (USA)	Swath width : 2795 Km (+- 51 degree) Wavelength : 304.0, 312.5, 325.0, 317.5, 332.6, 350.0 IFOV : 3 X 3 degree (42 X 42 Km) Data rate : 400 bps	Observation of distribution of ozone and sulfur dioxide by volcanic interference. Provide atmospheric correction for OCTS data
POLDER	CNES (France)	Swath width : 1440 X 1920 Km Matrix CCD (228 X 384 pixel) Wavelength : 435, 670, 880 nm (3 different polarization directions) 490, 520, 565, 765, 950 nm (no polarization) IFOV : 6 mrad (5Km) Data rate : 1.1 Mbps	Observation of bidirectionality and polarization of the solar radiation reflected by the atmosphere
IMG	MITI (Japan)	Swath width : 20 Km Wavelength : 3 - 15 micro m IFOV : 0.75 X 0.75 degree Data rate : 1 Mbps	Observation of CO2, CH4, N2O and other greehouse gases by IR Michelson Interferometer.
ILAS	Environmental agency (Japan)	Wavelength : 0.753 - 0.784, 4.1 - 6.9, 7.3 - 11.9 micro meter Observation altitude : 10 - 60 Km FOV : +- 15 degree(vertical), +-10 (horizontal) Data rate : 0.5 Mbps	Observation of the limb atmospheric species density over high latitude area.
RIS	Environmental agency (Japan)	Cube corner retoreflector : 50 cm (diameter)	Measurement of ozone, fluorocarbon, carbon dioxide etc. by laser beam absorption technique, transmitted from ground station and reflected by the retroreflector on ADEOS.

APPENDIX : Description of Candidate Payload for Next Japan's EOS

AMSR (Advanced Microwave Scanning Radiometer)

A multi-frequency microwave radiometer for measurement of various atmospheric and oceanic parameters concerning H_2O, such as precipitation, water vapor, cloud water, sea surface temperature, sea ice and sea wind speed

HERITAGE :	MSR (MOS-1)	
PERFORMANCE :	Frequency :	6 GHz to 90 GHz (6 frequencies). (1.4 GHz to 180 GHz as an option)
	Polarization :	vertical and horizontal
	Temperature resolution :	0.2 - 1 K (Goal)
	Radiometric accuracy :	1 K (Goal)
	Antenna aperture :	2 m

GLI (Global Imager)

An imaging spectrometer for global monitoring of biological and physical processes and stratospheric ozone at the spectral range from ultraviolet to thermal infrared

HERITAGE :	VTIR (MOS-1) OCTS (ADEOS)	
PERFORMANCE :	Band :	more than 20 bands from UV to thermal IR
	Band width :	10 to 20 nm
	S/N :	< 1000
	Swath :	> 1800 km
	IFOV :	< 1 km

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APPENDIX : Description of Candidate Payload for Next Japan's EOS (continued)

Monitoring Instruments for Atmospheric Chemical Composition

TERSE (Tunable Etalon Remote Sounder of Earth)

A high spectral resolution near infrared spectrometer for global measurement of tropospheric minor species (CH_4, H_2O, N_2O, CO_2) profiles with high accuracy by the method of scanning tunable etalon

TOMUIS (3-D Ozone Mapping with UV Imaging Spectrometer)

An imaging spectrometer for three dimensional mapping of stratospheric ozone distribution by measuring backscatter of ultraviolet spectrum using two dimensional detectors array for resolving spectra and area

SLIES (Stratospheric Limb Infrared Emission Spectrometer)

A Fourier transform Michelson interferometric spectrometer used for measurement of infrared emission of stratospheric and tropospheric minor species with looking at limb and nadir

HERITAGE : IMG (ADEOS)

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APPENDIX : Description of Candidate Payload for Next Japan's EOS (continued)

E-LIDAR (Experimental LIDAR)

An experimental active optical sensor for measurement of water vapor profile as a differential absorption lidar (DIAL) and of ice-sheet and sea surface heights with high accuracy as a laser altimeter

IMB' (Investigater of Micro-Biosphere)

A multi-band imaging radiometer from visible to near infrared for measurement of ecological environment with high spatial resolution

HERITAGE : MESSR (MOS-1)
AVNIR (ADEOS)

ADALT' (Advancd Radar Altimeter)

A two frequencies radar altimeter for measurement of geoid, ocean wave and polar ice, and for contribution to the research of oceanic circulation and sea ice / ice sheet extent

PR (Precipitation Radar)

An active microwave sensor for three dimensional measurement of rain rate in global scale, and for contribution to the research of hydrological circulation

HERITAGE : PR (TRMM)

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