5 Ground Data System

5.1 Objectives of JEM/SMILES Ground Data System

JEM/SMILES Ground Data System must have the following functions as similar to other ground data systems for earth observing satellites.

- Operation Planning
- Commanding
- Housekeeping Telemetry data watching
- Data processing, archiving and distribution
- Observation prediction and planning (for validation experiments)

The first two functions will have to be developed in close connection with JEM Operation System. The later two functions will be developed independently of JEM Operation System. The goal of SMILES Ground Data System is to support SMILES operation flawlessly, and to provide scientifically good SMILES data to users. Following requirements will be necessary to proceed to this goal within the limited SMILES experiment period.

- Extensive effort to improve data quality of SMILES product through data quality check, algorithm development and validation.
- Processing power enough to re-process and to improve data set quality until broad scientific acceptance.
- Seamless data distribution to potential data users.

It is assumed that the SMILES operation extends only one year (and may be extended up to two years). Thus, those efforts should be focused on at (and prior to) SMILES operation. If there will be 3 major version up during 12 months, the required processing power must be much higher than the equilibrium processing speed, which means data is processed just as much as downlinked.

SMILES data will be distributed in L1, L2, and L3 format. Table 5.1 lists characteristics and volume of these data sets. Typical scientific users will require daily gridded L3 data. Several users will compare their own observed data to SMILES L2 vertical profile data. Several higher, so-called L4, data sets, such as monthly mean data will be processed as a part of standard products. Data distribution policy of SMILES is as open as possible, similar to recent other earth observation programs of NASDA and other space agencies. Distribution of L0 and L1 data might be limited to the groups having agreement with NASDA, due to huge data volume (and limited SMILES program budget).

5.2 JEM Operation System

Figure 5.1 shows an overview of JEM Operation System and its interface to JEM experiment users. JEM Operation System will be responsible to (1) Mission Data Interface, (2) Data Management, (3) Operation Planning, (4) Commanding, and (5) House Keeping Telemetry Data Checking. These functions and its relation to JEM users, such as SMILES team, will be specified in the "Mission Operation Interface Specification (MOIS)" document.

JEM Operation System at Tsukuba Space Center (TKSC) will receive downlinked data and archive all raw data. JEM Operation System will handle mission data interface

Table 5.1 SMILES data sets

Data Type	Description	Potential Users	Volume/year	Distribution
Raw	Unedited Binary Packets	inhouse	120 kbps 1.24 GB/day 317 GB/year	NA
L0	edited engineering data file	instrument team	20 MB/file 1.24 GB/day 317 B/year	tape etc.
L1	calibrated physical data file spectral brightness temperature (K)	retrieval	2.48 GB/day 634 GB/year	tape etc.
L2	vertical profile of species ppmv or cm^{-3}	validation	2.82 MB/day/species 56.4 MB/day 14.1 GB/year	internet DVD/ROM
L3	grid data of species ppmv or cm^{-3}	general	2-3 MB/day/species 40-60 MB/day 14-20 GB/year	internet DVD/ROM

to SMILES team. SMILES house keeping telemetry data and command plan by SMILES team will be checked in detail by JEM Experiments Operation Support Client and/or user system connected to the External User Interface.

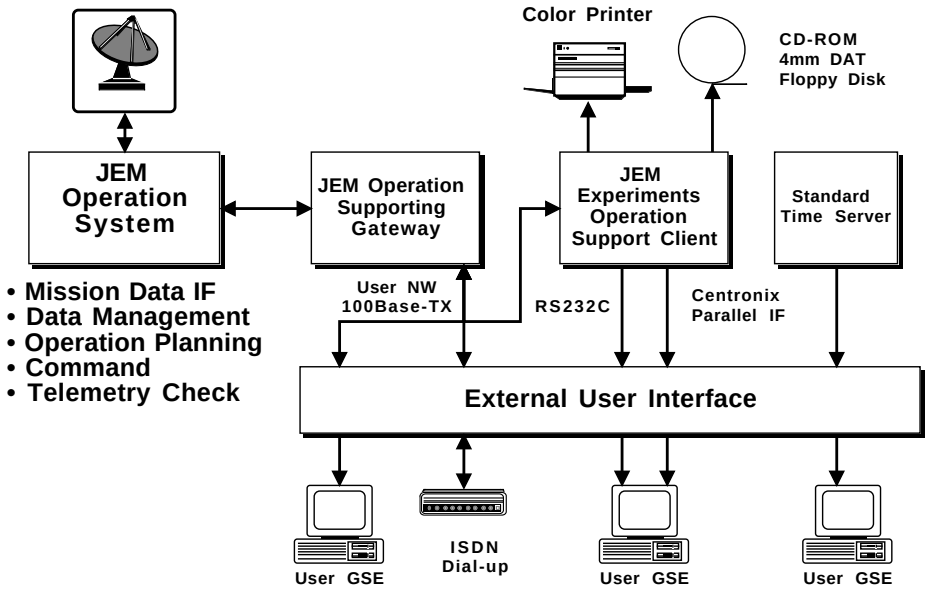

Figure 5.1 JEM Operation System and its relation to JEM Experiment users.

5.2.1 Operation Planning

JEM Operation System will arrange an operation plan of JEM and JEM experiments including SMILES, considering (1) request from experiments, (2) resource limitation, such

as power, downlink capacity, zero gravity condition, astronauts man power, etc, and (3) limitation from space station. Outline of this operation plan will be pre-determined before the launch of SMILES in the MOIS and the "Mission Operation Implementation Plan (MOIP)" document. But, details of operation will be revised monthly, weekly, and daily basis, since the operation of SMILES, JEM, and ISS will be interfered by reasons such as docking of the Space Shuttle. Figure 5.2 shows a concept of the operation planning for JEM.

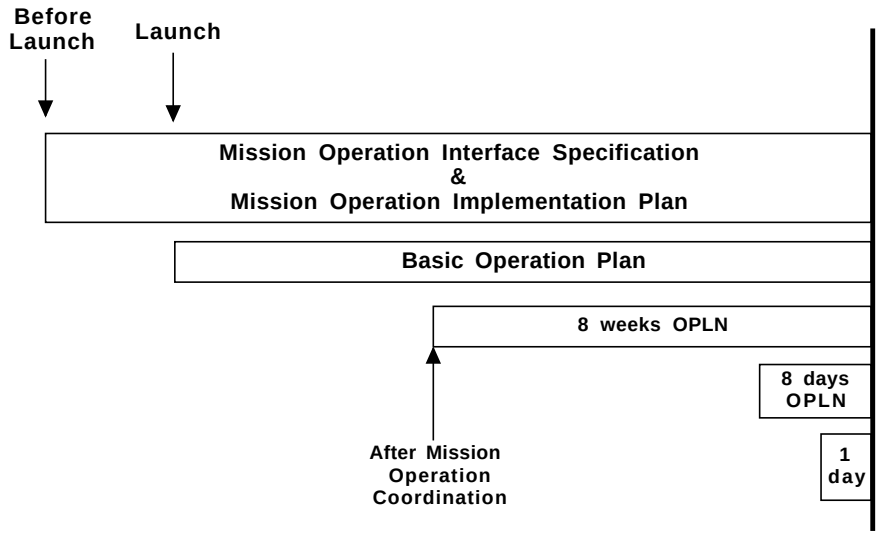

Figure 5.2 Concept of operation planning for JEM.

5.2.2 Commanding

JEM Operation System will send command sequence to JEM experiments based upon the decided JEM operation. This command sequence should be checked carefully everytime, whether it is not violating commanding rules for all other experiments on JEM, and ISS. Details of commanding will be described in the "Spacecraft Orbital Operation Handbook (SOOH)". The SOOH covers background of sensor design in addition to the details of commanding rules, housekeeping data and trouble shooting.

5.2.3 House Keeping Telemetry Data Checking

JEM Operation System will receive, archive and real-time check house keeping (HK) telemetry data, and analyze their trend. JEM Operation System will not check instrument information contained within SMILES mission data. SMILES will have a limited autonomous function, such as system abortion at cooler failure. Other anomalies will be handled by the operator at JEM Operation System based upon the SMILES SOOH.

5.3 Functions and Data Flow between ISS and SMILES ground data system

Fig 5.3 shows overall data flow of JEM/SMILES mission. Data acquired by SMILES will be multiplexed with data of other experiments of JEM. The multiplexed data will be downlinked from International Space Station (ISS) through geostationary data relay satellites to ground receiving stations. The multiplexed downlinked data are processed at JEM Operation Center at NASDA/TKSC, to RAW data of each JEM experiments. The SMILES RAW data will be provided to SMILES Ground Data System. Data transmission through these data relay system should be carried out without data loss against continuous operation of SMILES.

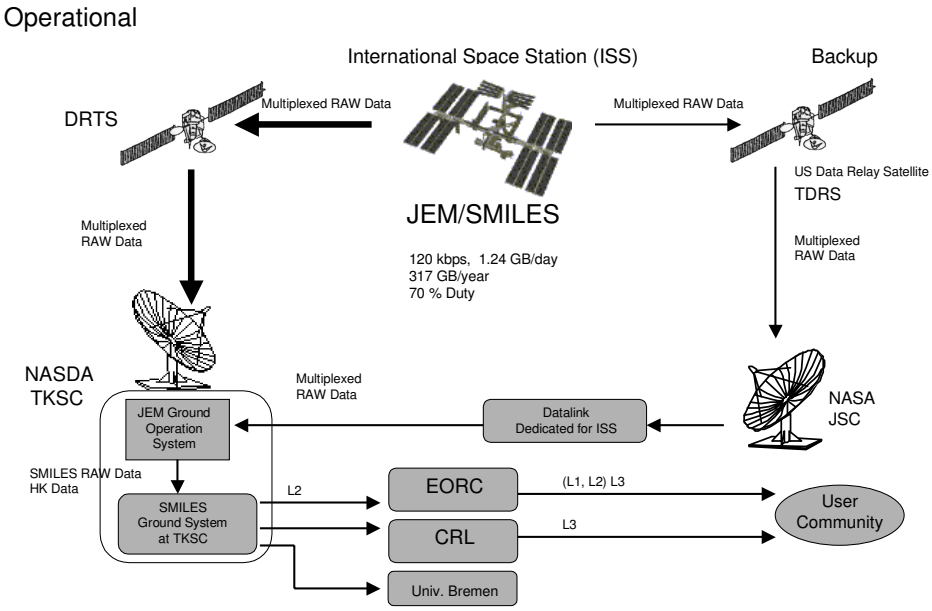

Figure 5.3 SMILES data flow.

5.3.1 JEM/SMILES to Receiving Stations

SMILES RAW data consists of HK data (House Keeping data, 16 kbps) and SMILES Mission Data (about 120 kbps). SMILES Mission Data (and HK data) will use CCSDS ver 1 packet format. The SMILES RAW data will be multiplexed with data of other instruments/experiments of JEM. The multiplexed JEM data will be downlinked immediately when data relay satellites are available. When data relay satellites are not available, the multiplexed data are stored in JEM common data storage, which can store data up to 60 minutes. Two data relay satellites are planned for downlink of JEM, primarily Japanese DRTS will be utilized, and US's TDRS will be utilized as an option. The DRTS

will then downlink to NASDA/TKSC in Tsukuba/Japan, and the TDRS will downlink to NASA/JSC in Houston/USA.

5.3.2 Receiving Stations to JEM Operation System at NASDA/TKSC

The downlinked data at JSC will be transferred to JEM Operation System through a data communication line dedicated to the JEM operation. All downlinked data will be collected and archived at JEM Operation System. Archiving of SMILES mission data (120 kbps) in JEM/OS will be tentative, and SMILES ground segment will have responsibility of archiving of SMILES data.

5.3.3 JEM Operation Center to SMILES Ground Data System

JEM RAW data collected at JEM Operation Center are processed and edited to RAW data of each JEM experiments. Following description on data handshake between the JEM Operation System and the SMILES Ground Data System (see Figure 5.4) are still TBD.

TBD number of CCSDS packets of SMILES RAW data are gathered to make a SMILES RAW data file in JEM Operation Center. The SMILES RAW data file is edited as first in and first out (FIFO) rule at JEM Operation Center, and there will be no further editing of CCSDS packets, such as sorting packets for observation time and deleting duplexed packets. The SMILES RAW data files will be stored as computer data files in a data distribution system of JEM Operation Center.

JEM Operation Center will send a data ready signal as an e-mail to SMILES Ground Data System and SMILES RAW data files are ready for data transaction. SMILES Ground Data System will make an ftp transaction to acquire a SMILES RAW data file from the data distribution system of JEM Operation Center. After successful ftp transaction, SMILES Ground Data System will send a data acquisition signal as an e-mail to JEM Operation Center. SMILES Ground Data System will check the acquired SMILES RAW data file, whether it was generated and transferred properly. SMILES Ground Data System will send a data certification signal as an e-mail to JEM Operation Center. JEM Operation Center will delete the JEM RAW data file in the data distribution system, after TBD days of the receiving of data certification signal.

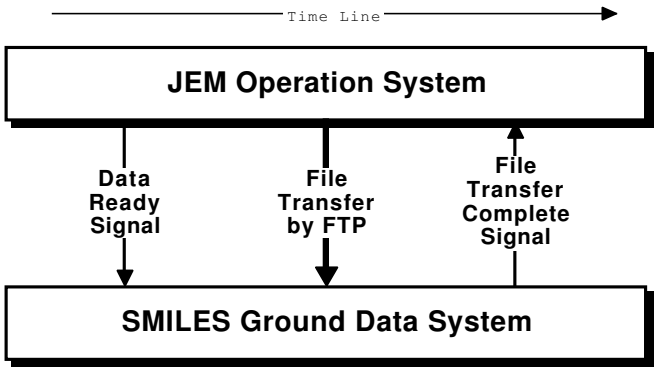

Figure 5.4 Data handshaking between JEM Operation System and SMILES Ground System.

5.4 Functions of SMILES Ground Data System

SMILES Ground Data System will be established at NASDA/TKSC (TBD). Currently three groups, NASDA/TKSC SMILES Mission Team, CRL, and NASDA/EORC are responsible for the development of SMILES Ground Data System. By considering physical contact with JEM Operation System, SMILES Ground Data System should be established at NASDA/TKSC. SMILES Ground Data System will have following functions: (1) operation planning, (2) commanding, (3) House Keeping telemetry data watching, (4) data processing, archiving, and distribution and (5) observation prediction and planning (for validation experiments).

Operation Planning and Commanding

Operation of SMILES will be categorized into the following three, (1) Initial check-out period operation, (2) Instrument Performance Check operation and (3) Normal Observation operation. Operation plan will be decided by SMILES mission team to fulfill the mission success criteria of SMILES program. Operation plans are examined by SMILES mission team members and possibly by SMILES operation simulator program (TBD). Command sequences are then decided and send to JEM Operation System, but they might be revised or interfered by conditions of SMILES, JEM, ISS and ground segment, until actual real-time operation of SMILES.

House Keeping telemetry data watching

SMILES Ground Data System will have full house keeping capability of SMILES (, JEM and ISS, if necessary). JEM Operation System will watch only alert condition of SMILES. JEM Ground Data System will make caution signal when any status of HK and/or mission data of SMILES reach caution level or show abnormal trend. SMILES Ground Data System will analyze statistical feature and trend of SMILES instrument status.

Data processing, archiving, and distribution

• SMILES RAW Data Processing

SMILES RAW data files will be acquired and processed by SMILES RAW Data Processor within SMILES TKSC Data System. SMILES RAW Data Processor will have a dedicated and isolated ethernet connection with JEM Operation Center. SMILES RAW Data Processor will make data transactions with JEM Operation Center only through this ethernet connection. SMILES RAW Data Processor temporarily stores SMILES RAW data files until TBD days after successful Level 0 (L0) data production.

If RAW Data transaction and other RAW data processing are not successful, SMILES RAW Data Processor will alarm to some of SMILES mission team members through e-mail and/or SMILES Mission Management Operation System. All log of transactions and other events of SMILES RAW Data Processor will be stored in one (or multiple) text format file(s). The log must contain at least following information; time-date of log creation, name of RAW data file, time-date of RAW data file creation, beginning and end of time-date of receiving within a RAW data file, and a status flag. The log file(s) will consist of text lines separated by a delimiter of Operating System, and a full set of records of transaction must have been written in a single text line, not in multiple text lines. The records in one text line must be organized, as any information column can be a key of sorting and/or filtering of commands of Operating System.

• L0 Data Production Processing

The RAW data in the CCSDS packet format will be depacketed and converted into the L0 data arranged in a time series after quality estimation. Continuity and flawlessness will be checked and information for data loss will be recorded. There may also be overlaps to be removed, which can be created when the data transfer via satellite is suspended. The data obtained during a quarter of an orbit operation will be edited into one file. The

content of L0 data is the SMILES observation and the instrument HK data in addition to information about time and date.
• L1 Data Production Processing
The L0 data will be converted into engineering values and processed into calibrated limb spectral radiances by using the calibration data. Anomalous data will be checked and marked before processing. The ancillary data such as the tangent altitude and the position of the observation will be created and added as a part of L1 data products.
• L2 Data Production Processing
The height profiles of geophysical quantities such as composition and temperature and their errors are retrieved from the SMILES L1 data using the optimal estimation method. The data volume is estimated to be 2.82 MB/day/species. The L2 data processing will be performed in NADA/EORC, CRL and University of Bremen, independently.
• L3 Data Production Processing
The gridded daily, weekly and monthly maps for all species will be produced in CRL, NASDA/EORC and University of Bremen, respectively. The SMILES data will be archived and distributed in L1, L2 and L3 format though the distribution of L0 and L1 data might be limited to those having agreement with NASDA or CRL due to huge data volume. There remains a security issue, but users can access SMILES L2 and L3 data products created at CRL, NASDA/EORC and University of Bremen through internet. The data stored in DVD/ROMs will also be distributed to users.
Observation prediction and planning
Since the SMILES data products must be verified through validation activities, timely and accurate announcement of near future SMILES observation is crucial for good coincidence of validation measurements. Orbit characteristics, especially attitude of ISS, will change and fluctuate even few days after the observation prediction. Thus, observation prediction must be updated frequently, perhaps daily.

5.5 Consideration on Computation in the JEM/SMILES L2 Data Processing

The task of the SMILES L2 data processing algorithm is to produce the geophysical parameters such as concentration profiles of targeted gases, temperature and pressure from measured radiance. As described in the previous chapter, the retrieval method adopted in the SMILES data simulator is Optimal Estimation Method (OEM) [*Rodgers*, 1976]. We believe this retrieval strategy for SMILES is similar to the past and the near future millimeter and sub-millimeter limb-sounding programs [*Levesey and Wu*, 1999], and it is, thus, well established already. In the following, we briefly discuss the performance requirements for the SMILES L2 data processing.

The computational efficiency is determined by both the number of matrix operations and the numerical cost for updating an expected measurement and a weighting function. In the forward model, an efficient method for calculating the Voigt function is required. For this purpose we use Hui 's rational approximation [*Hui et al.*, 1978][*Suzuki*, 1994]. The test result of forward model calculation (brightness temperature) for 61 rays is currently 77 sec (10 to 60 km, 1 km tangent height interval, using 400 MHz Pentium-III). It looks easy to improve computation speed to achieve requirements for operational condition, such as better than 10 sec, by using faster CPU. If these methods for fast computation of Voigt function are not acceptable in speed, table interpolation using such B-spline method in pressure and temperature will be applied as similar to the systems of ADEOS/ILAS or ADEOS/IMG.

Let us turn our attention to the matrix operations. Let the size of the state vector be

$n \sim 150$ which may be typical for the simplest retrieval including the baseline parameters. The measurement vector is a set of observed radiance at scanned tangent altitudes. Since the SMILES limb scan will be done by taking spectral data from 10 to 60 km in the interval of ~ 2 km, the size of the measurement vector m becomes 26 times the number of selected frequency data from AOS's 1500 channels for a 1.2 GHz band. If $30 \sim 1500$ frequency data are used in retrieval, the dimension of the weighting function matrix becomes $(7.8 \times 10^2) \times 150 \sim (3.9 \times 10^4) \times 150$. As is easily seen from (4.14) in Chapter 4, the number of floating point operations per iteration in the case of $m > n$ is estimated as $\sim (mn^2 + n^3)$, where it is assumed that the error covariance matrix is diagonal and $\mathbf{S}_a^{-1}$ is prepared in advance. Note that mn^2 corresponds to the operation $\mathbf{K}^T\mathbf{S}_\epsilon^{-1}\mathbf{K}$ while n^3 comes from the inversion of the Hessian. Then the number of operations needed to perform a retrieval turns out to be $2.1 \times 10^7 - 8.8 \times 10^8$, which corresponds to execution time, $0.02 - 0.88$ sec, on a 1 Gflops/sec computer in an ideal situation. If a couple of species or more have to be solved together, the execution time increases mainly according to $\sim mn^2$. For example, for an extreme case $n = 1000$ and $m = 1500$, the execution time becomes 40 sec times the number of iteration and the weighting function occupies 0.3 GB. Nevertheless OEM still seems to work as an efficient retrieval algorithm.

Table 5.2 Estimated performance requirements (GFlops and memory size) for SMILES Data System compared to those of EOS/MLS program.

	JEM/SMILES	EOS/MLS
L0 Processing	Desktop WS Performance 8 GB Disk and network I/O limited	Desktop WS Performance 8 GB Disk and network I/O limited
L1 Processing	Desktop WS Performance 8 GB Disk and network I/O limited	Desktop WS Performance 8 GB Disk and network I/O limited
L2 Processing	4 GFlops (peak performance) 20 GFlops (with a margin for reprocessing) > 32 GB Computation limited	1 GFlops (true performance) > 16 GB Computation limited

The detail design of SMILES Data Processing is not specified yet. As described above, the most computing intensive part of SMILES retrieval will require 1 GFlops, 'net' performance. Actual data processing will require 5-6 times performance for re-processing after version ups etc. One GFlops net performance should be measured by Linpack 100 benchmark since the nature of SMILES retrieval scheme. One GFlops net performance is usually equal to 3-4 GFlops peak performance. See Table 5.2. Overall computation requirement is very feasible even from today's standard, and it will not be expensive at the time of SMILES operation. Data archiving and distribution look quite feasible, since the data volume of SMILES is moderate. Data retrieval scheme for the sub-millimeter limb sounder has been already established for other space programs, and thus we see no difficulty on development of SMILES data retrieval system.

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