Chapter 6 Data Used in Remote Sensing

6.1 Digital Data

Images with a continuous gray tone or color, like a photograph are called analog images. On the other hand, a group of divided small cells, with integer values of average intensity, the center representing the cell's value, is called a **digital image**. The spatial division into a group of cells is called **sampling** as illustrated in Figure 6.1.1, while conversion of analog images into integer image data is called **quantization** as illustrated in Figure 6.1.2 and 6.1.3.

An individual divided cell is called a pixel (picture cell). The shape of the cell is usually square for easy use in a computer, though triangular or hexagonal can also be considered.

A digital image has coordinates of pixel number, normally counted from left to right, and line number, normally counted from top to bottom.

The most important factor in sampling is pixel size or sampling frequency. If the pixel size is large or the sampling frequency is long, the appearance of the image becomes worse, while in the reverse case the data volume becomes very large. Therefore the optimum sampling should be carefully considered.

Shannon's sampling theorem, for specifying the optimum sampling, is given as follows.

"There will be no loss of information if sampling is taken with a half frequency of the maximum frequency involved in the original analog frequency wave."

Let the analog intensity be f and the unit intensity v(>0) as divider in quantization. Let the quantized intensity be f_d, fd is given by n as illustrated in Figure 6.1.2. The difference between f and f_d is called **quantization error**.

The question is how to determine the number of quantization levels or the unit intensity as divider. If the number of levels is too small, the quantization error will increase. In the reverse, the data volume increases with informationless data because of the noise level, as shown in Figure 6.1.3.

For example in Figure 6.1.3, the quantization should be divided by a level larger than that of the noise. In this example, four levels would be an appropriate quantization.

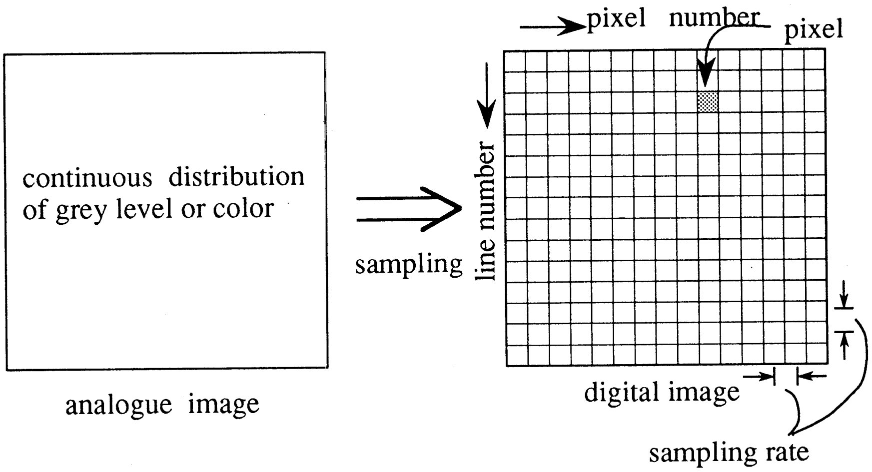
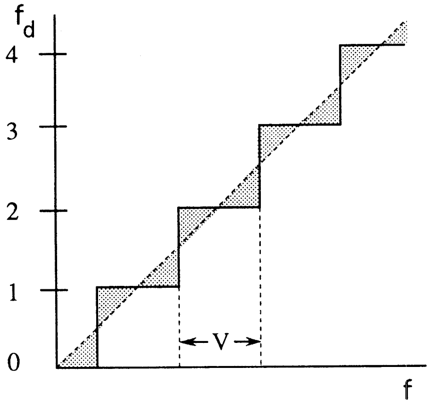


Figure 6.1.1 Concept of sampling



f : analogue intensity

f_d : quantized intensity

V : unit intensity

n : integer

$(n-0.5)V \leq f < (n+0.5)V \rightarrow f_d = n$

quatization error = $f - f_d$ (shaded part)

Figure 6.1.2 Concept of quantization

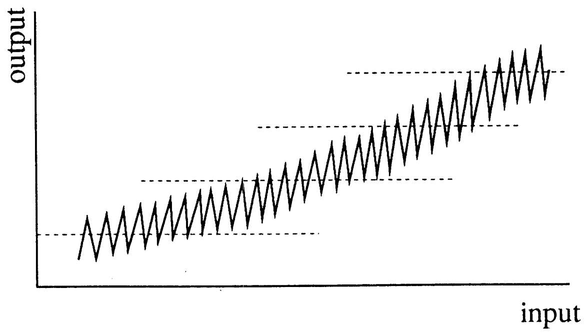


Figure 6.1.3 Quantization in the case of a signal containing a noise

6.2 Geometric Characteristics of Image Data

Remote sensing data are data digitized by a process of sampling and quantization of the electro-magnetic energy which is detected by a sensor. In this section, geometric characteristics of sampling are described, while radiometric characteristics by quantization are explained in 6.3.

IFOV (instantaneous field of view) is defined as the angle which corresponds to the sampling unit as shown in Figure 6.2.1. Information within an IFOV is represented by a pixel in the image plane.

The maximum angle of view which a sensor can effectively detect the electro magnetic energy, is called the **FOV** (field of view). The width on the ground corresponding to the FOV is called the **swath width**.

The minimum detectable area, or distance on the ground is called the **ground resolution**. Sometimes the projected area on the ground corresponding to a pixel or IFOV is also called the ground resolution.

In remote sensing, the data from a multiple number of channels or bands which divide the electromagnetic radiation range from Ultra Violet to Radio Waves are called **multi-channel data, multi-band data** or **multi- spectral data**.

In general, multi-channel data are obtained by different detectors as shown in Figure 6.2.2. Because the detectors are located at slightly different positions, and the light path of different wavelengths is a little different from each other, the images of multi-channel data are not identical in geometric position. To correct such geometric errors between channels is called registration.

The term registration is also used for registration of multi-temporal (or multi-date) images.

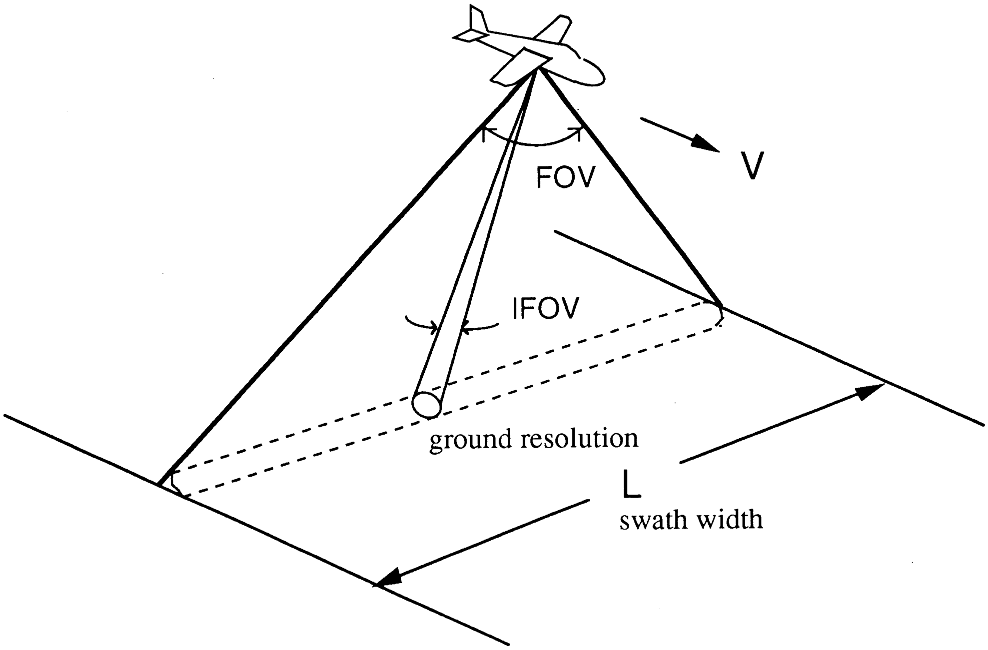


Figure 6.2.1 FOV and IFOV

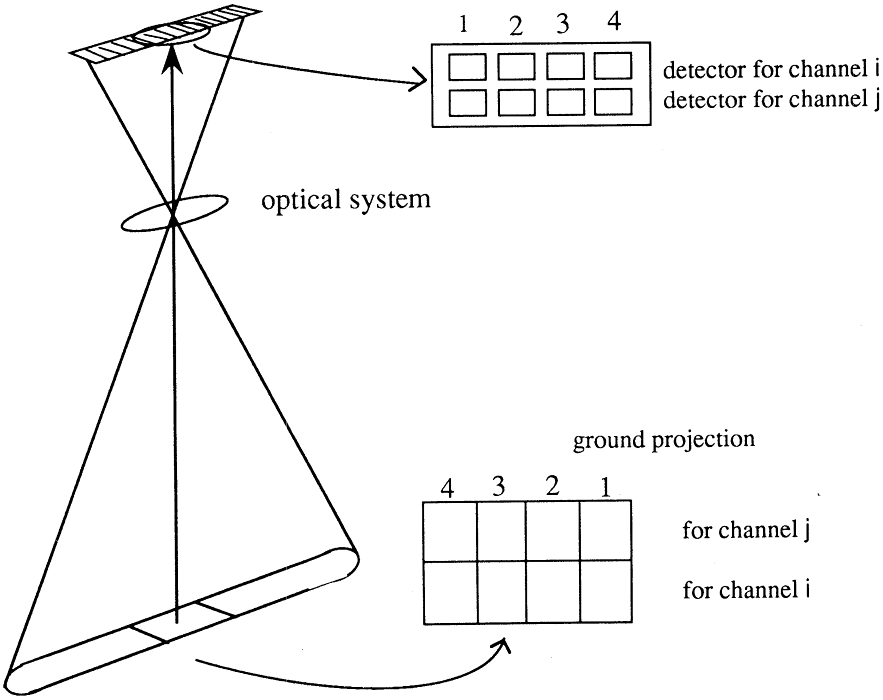


Figure 6.2.2 Relationship between a detector and its ground projection

6.3 Radiometric Characteristics of Image Data

Electromagnetic energy incident on a detector is converted to an electric signal and then digitized. In this quantization process, the relationship between the input signal and the output signal is generally represented as shown in Figure 6.3.1. In this curve the left part corresponds to the insensitive area, with less response, while the right part is the saturated area with almost constant output regardless of the input intensity.

In the central part, there is almost a linear relationship between the input and the output. The approximation to a linear relationship is called **linearity**. The range of the linear part or the ratio of maximum input to minimum input is called the **dynamic range**, which is usually expressed in dB (see 2.2).

One should be careful of the noise level in the case of quantization, as explained in 6.1. The ratio of effective input signal S to the noise level N is called the **S/N ratio** (signal to noise ratio), which is given as follows.

$$S / N \text{ ratio} = 20 \log_{10} (S/N) \quad [\text{dB}]$$

In conclusion, quantization is specified by the dynamic range and the S/N ratio. Information contained in digitized image data are expressed by **bit** (binary digit) per pixel per channel.

A bit is a binary number, that is 0 or 1. Let the quantization level be n, then the information in terms of bits is given by the following formula.

$$\log_2 n \text{ (bit)}$$

In remote sensing, the quantization level is normally 6, 8 or 10 bits as shown in Table 6.3.1. For computer processing, the unit of **byte** (1 byte = 8 bits;integer value 0-255 ; 256 gray levels) is much more convenient. Therefore remote sensing data will be treated as one or two byte data.

The total data volume of multi-channel data per scene is computed as follows.

Data Volume(byte) = (line number) x (pixel number) x (channel number) x (bits) /8

Output data usually corresponds to the observed radiance detected by the sensor. The absolute radiance is converted by a linear formula from the observed radiance (see 9.1). The parameters are usually listed in the User's Manual for the particular remote sensing system.

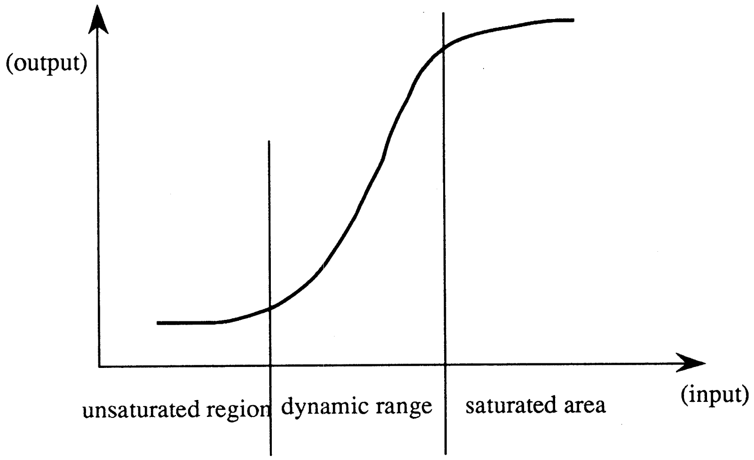


Figure 6.3.1 Input-output charactaristic curve

Table 6.3.1 Quantization level of remote sensing data

sensor	satellite	level(bit)	descriptions
TM	Landsat	6	8bits data after radiometric correction
MSS	Landsat	8	
HRV(XS)	Spot	8	
HRV(PA)	Spot	6	
AVHRR	NOAA	10	both 10 and 16 bits data are available at distribution
SAR	JERS-1	3	real 3 bits, imaginary 3 bits

6.4 Format of Remote Sensing Image Data

Multi-band image data are represented by a combination of spatial position (pixel number and line number) and band.

The data format for multi-band images is classified into the following three type, as shown in Figure 6.4.1.

a) **BSQ** format (band sequential) image data (pixel number and line number) of each band are separately arranged.

b) **BIL** format (band interleaved by line) line data are arranged in the order of band number and repeated with respect to line number.

c) **BIP** format (band interleaved by pixel) A set of multi-band data with respect to each pixel arranged spatially by pixel number and line number.

For color image output, BSQ format would be convenient because three bands will be assigned to R(red), G(green) and B(blue). However BIP format would be better for classification by a maximum likelihood classifier because multi-band data are required pixel by pixel for the multi-variable processing. BIL would be a compromise between BSQ and BIP.

Remote sensing data usually includes various annotation data in addition to image data. Since 1982, satellite image data have been provided in a standard format called **World Standard Format**, or **LTWG format** (specified by Landsat Technical Working Group).

The World Standard Format has the data structure called **super structure** with three records of volume descriptor, file pointer and file descriptor which describe the contents of the data (see 6.5).

Either BSQ or BIL format is chosen in the World Standard Format.

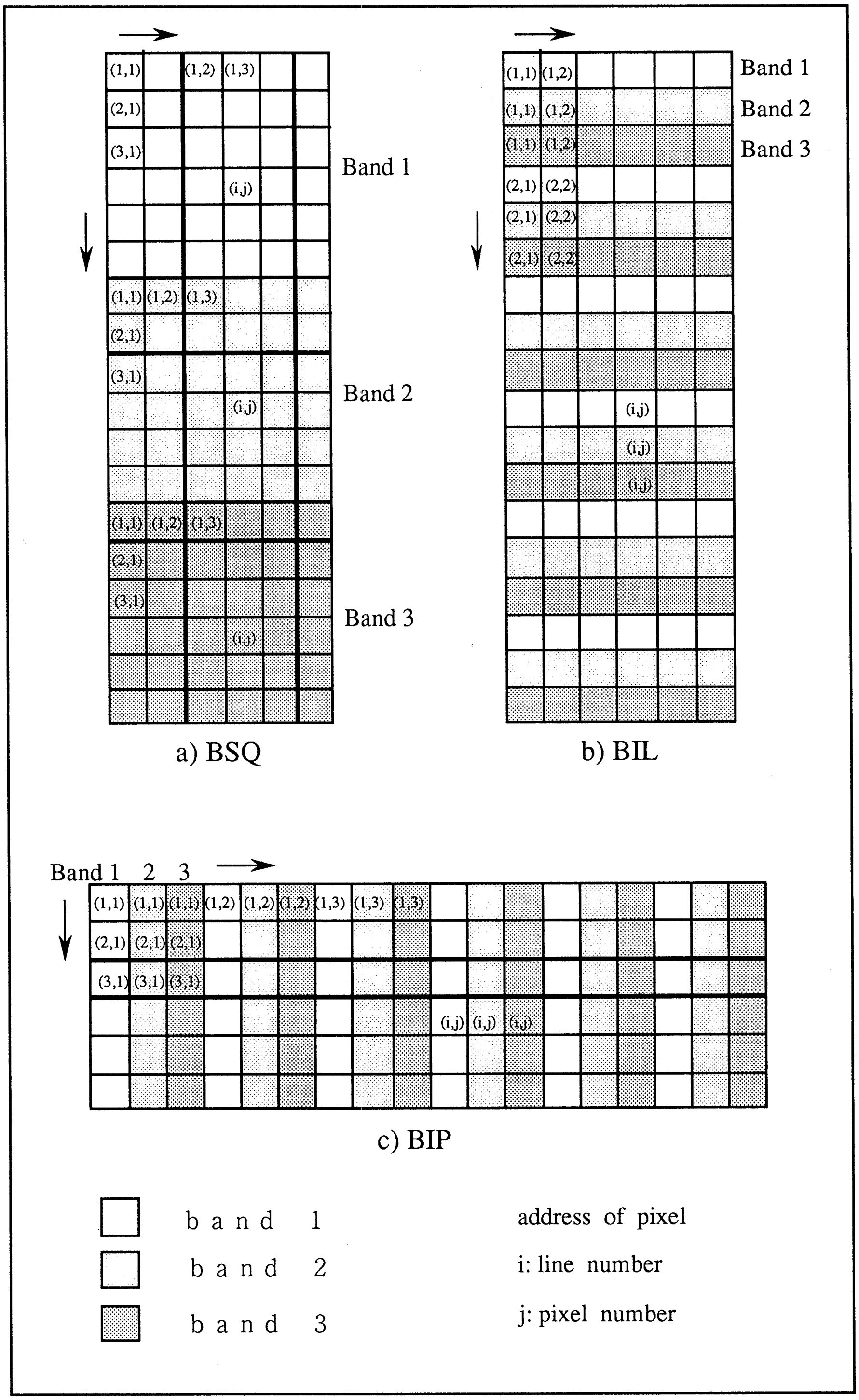


Figure 6.4.1 Image data format (in the case of 3 separate bands)

6.5 Auxiliary Data

An image scene is composed of multiple files, each of which is composed of multiple records. Data other than image data in the files, are called **auxiliary data**.

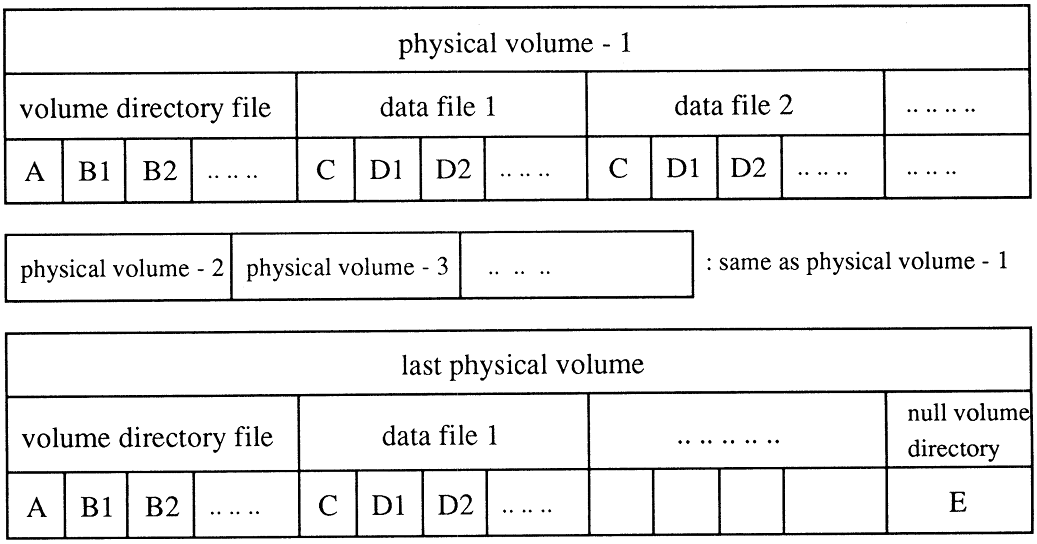
The auxiliary data involves descriptions of file, image data, platform, sensor, data processing and other data, including telemetry.

Figure 6.5.1 shows the basic configuration of the World Standard Format or LTWG format with the files and the records. The files and the records in the figure are as follows.

Reader file: header record, ancillary record, annotation record etc.
Image file: image record (line information and spectral data)
Trailer file: trailer record (quality of data)
Supplemental file: information on satellite, detector, data correction etc.

Table 6.5.1 shows the contents of auxiliary data. There is a text record in which any comment can be described. In the LTWG format, the text record is located in the volume directory file.

The LTWG format has no fixed specification on the content of each record, while the **CEOS Format** (Committee on Earth Observation Satellite) specifies the standard content of a record, which will be utilized more than LTWG in the future.



where : A : volume description record
B* : file pointer record
C : file descriptor record
D* : image data record
E : null volume directory record

Figure 6.5.1 LTWG format

Table 6.5.1 Contents of auxiliary data

volume descriptor (A)	structure of volumes, description on data in all volumes, description on each volume
file pointer (B)	location, kind, size for each file in a volume
text record (B, D)	comments described by data distributor
file descriptor (C)	number of records, length of records, data position, explanation on data for a file
header record (D)	scene description (location of scene center, time, correction method & level, number of bands, etc.)
ancillary record (D)	data for correction process (nadir, WRS, projection method, skew angle, attitude data of satellite, etc.)
annotation record (D)	annotation for scene described by character data
image record (D)	line information, spectral data
trailer record (D)	quality of data
supplemental file (D)	detector, coefficients for geometric correction, orbit data, other telemetry data

(A) ~(D) corresponds to A~D in figure 6.5.1, respectively

6.6 Calibration and Validation

Remote sensing data involves many radiometric errors resulting from sensitivity of detector, atmospheric condition, alignment of detectors and so on. **Calibration** is defined as the correction of the observed data, or relationship, into physically meaningful data, or relationship, by using a reference. For example, calibration involves the correction of observed data into absolute irradiance, reflectance or actual temperature.

Calibration can be classified into two types; ground calibration and on-board calibration, as shown in Table 6.6.1. The ground calibration data are measured before launch with a halogen lamp for visible and reflective infrared, and a black body for thermal infrared, which are normally described in the User's Manual.

The on-board calibration data are obtained on board after launch with on board references such as lamp and blackbody as well as physically known or constant objects such as sunlight, shadows on the ground and space with low temperature. The on board calibration data are transmitted from the satellite to ground receiving stations, together with the image data.

Table 6.6.2 shows the three calibration levels; interband calibration, band-to-band calibration, and absolute calibration.

In the case of NOAA AVHRR data, the ground calibration data are used for calibrating visible and near infrared data, while on-board calibration data are used for calibrating thermal data. Twelve lamps provide the ground calibration data, by which image data can be converted to Albedo. Thermal data can be converted to brightness temperature with the two reference temperature data of space (-270℃) and black body (15℃) measured by a platinum resistance thermometer (see Figure 2.10.1).

The brightness temperature obtained after calibration involves atmospheric influences. Therefore **atmospheric correction** is necessary. There are two types of atmospheric correction; a theoretical approach using an atmospheric model, and an empirical approach with ground truth data which are measured simultaneously with the satellite orbit.

In the latter case, so called **validation** data should be collected as ground data, for example, observed sea surface temperature from boats and buoys.

Validation is classified into three types; instrument specification, physical quantities and practical usages as shown in Table 6.6.3. Nevertheless, validation should be linked with ground data as explained in the next section 6.7.

Table 6.6.1 Types of calibration

type	acquiring time	reference radiation targets
ground calibration	before launch	visible - reflective infrared ; halogen lamp thermal infrared ; black body
on board calibration	after launch	visible - reflective infrared ; on board lamp or sunlight (high level) shadows on the ground (low level) thermal infrared ; on board black body (high level) space (low level)

Table 6.6.2 Calibration levels

level	reference radiative targets
interband calibration	For sensors which detect with different elements, such as Landsat TM. To determine the sensitivity ratio of each element.
band - to - band calibration	To determinate the sensitivity ratio of elements between bands.
absolute calibration	To determinate the absolute sensitivity of elements

Table 6.6.3 Types of validation

type	contents
instrument specification	to compare measured values with designed values concerning instrument specification (S/N, dynamic range, resolution, registration, noise level, etc.)
physical quantities	to check accuracy of some physical quantities from satellite data (reflectance factor, sea surface temperature, etc.)
practical usages	to estimate the efficiency of practical usage of physical quantities derived from satellite data (map generation, weather forecast, etc.)

6.7 Ground Data

Ground data, in some cases called **ground "truth"** is defined as the observation, measurement and collection of information about the actual conditions on the ground in order to determine the relationship between remote sensing data and the object to be observed. Investigation on the sea is sometimes called **sea truth**. Generally ground data should be collected at the same time as data acquisition by the remote sensor, or at least within the time that the environmental condition does not change. It should not be inferred that the use of the word "truth" implies that ground truth data is not without error.

Ground data is used as for sensor design, calibration and validation, and supplemental use, as shown in Figure 6.7.1.

For the sensor design, spectral characteristics are measured by a spectrometer to determine the optimum wavelength range and the band width.

For supplemental purposes, there are two applications; analysis and data correction. The former case, for example, is ground investigation, at a test area, to collect training sample data for classification. The latter case, for example, is a survey of ground control points for geometric correction.

The items to be investigated by ground data are as follows.

a. Information about the object type, status, spectral characteristics, circumstances, surface temperature etc.

b. Information about the environment, the sun azimuth and elevation, irradiance of the sun, atmospheric clarity, air temperature, humidity, wind direction, wind velocity, ground surface condition, dew, precipitation, etc.

Depending on the purpose, the above items and the time of ground investigation should be carefully selected.

Ground data will mainly include identification of the object to be observed, and measurement by a spectrometer, as well as visual interpretation of aerial photographs and survey by existing maps, and a review of existing literature and statistics.

Figure 6.7.2 shows data collection from various altitudes including ground data.

As the collection of ground data is time consuming as well as expensive, it is best to establish a **test site** for sensor design, calibration and validation, and data correction. The test area should be carefully selected with respect to ease of survey, variety of features present, weather condition and so on.

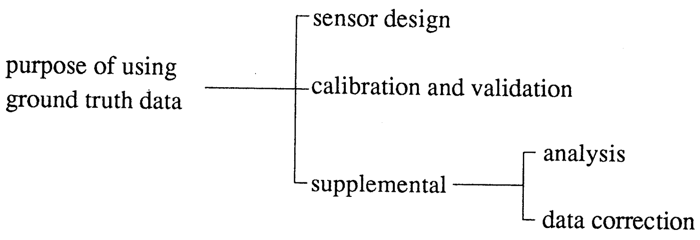


Figure 6.7.1 Purpose of using ground truth data

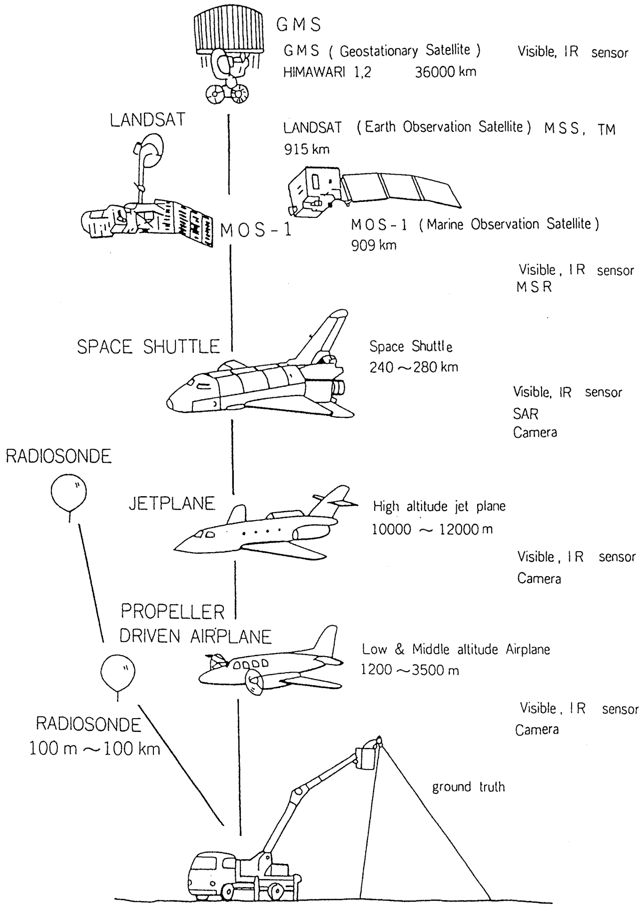


Figure 6.7.2 Data collection from various altitudes

6.8 Ground Positioning Data

In order to achieve accurate geometric correction, ground control points with known coordinates are needed. The requirements of ground control points are that the point should be identical and recognizable both on the image and on the ground or map, and its image coordinates (pixel number and line number) and geographic coordinates (latitude, longitude and height), should be measurable.

Use of a topographic map is the easiest way to determine the position of ground control point. However maps are not always available, especially in developing countries. In such cases, control surveys had previously been required.

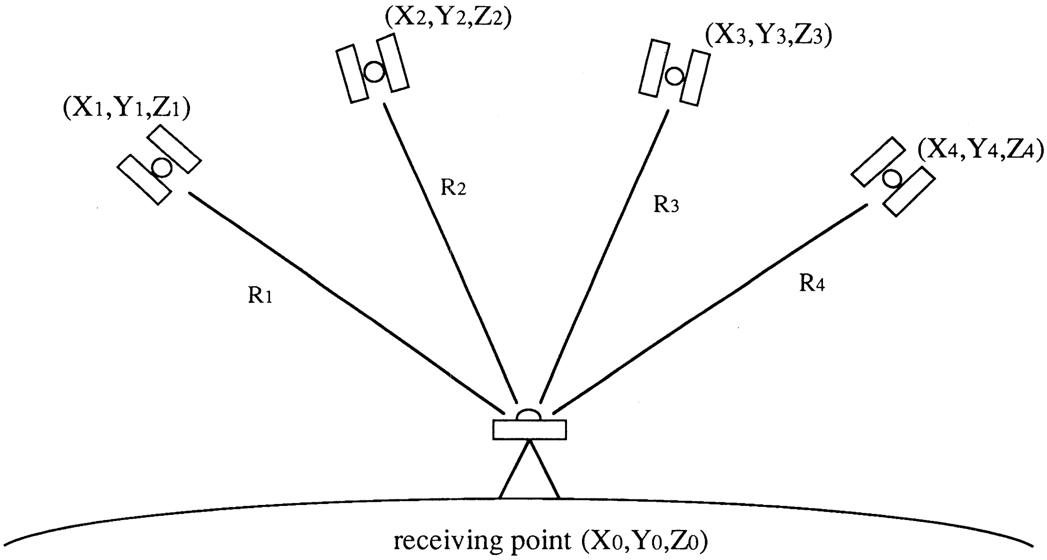
Today, however **GPS** (global positioning system) can provide geographic coordinates in a short time using a GPS receiver to measure time information from multiple navigation satellites.

GPS is a technique, used to determine the coordinates of a GPS receiver which receives radio signals from more than four navigation satellites. The received navigation message includes exact time and orbit elements which can be converted into the satellite position.

Two methods can be used for positioning; single point positioning and relative positioning.

The single point positioning method determines the coordinates with the use of a single GPS receiver, as shown in Figure 6.8.1. The geodetic accuracy achieved is about 10-30 meters. The unknown variables are four; X_0, Y_0, Z_0 and Δt (clock-timing error of a receiver). Therefore at least four navigation satellites are necessary. GPS has 18 satellites in total, at an altitude of 20,000 km, with three satellites each in six different orbits, which enable any point on the earth to view at least four satellites.

The relative positioning method determines the relative relationship between a known point and an unknown point to the measured. In this case, at least two GPS receivers should be located at the same time. The accuracy is 0.1-1 ppm of the base length between a known point and an unknown point. It is about 2-5 cm in planimetric accuracy and 20-30 cm in height accuracy.



$$R_i = \sqrt{(X_o - X_i)^2 + (Y_o - Y_i)^2 + (Z_o - Z_i)^2} + C \cdot \Delta t \qquad (i=1 \sim 4)$$

Ri : distance between a satellite and a receiving point
c : speed of electromagnetic wave in space
Δt : clock-timing error of a receiver
unknowns : $X_o, Y_o, Z_o, \Delta t$

Figure 6.8.1 single point positioning

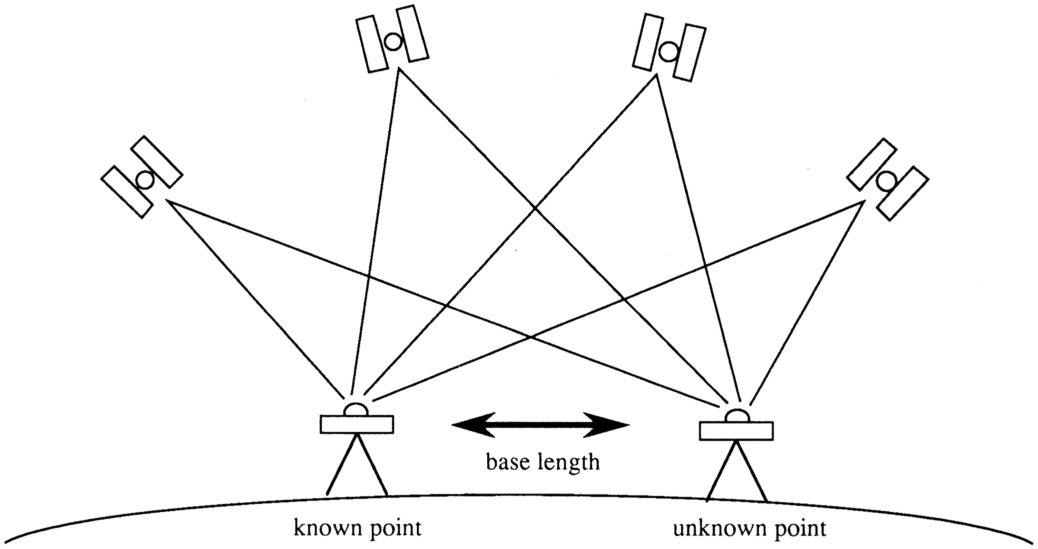


Figure 6.8.2 Relative positioning

6.9 Map Data

In remote sensing, the following maps are needed for particular objectives. Given below are requirements for satellite remote sensing. For airborne sensing one usually requires the larger scaled maps.

a. Topographic map:
1.25,000 or 1/50,000 topographic map will be best used to select ground control points and to extract DEM (digital elevation model) for digital rectification or the generation of a three dimensional view.

b. Thematic maps;
Land use, forest, soil, and geological maps etc. are used to collect training data for classification. A map scale of 1/50,000 - 1/250,000 is best for this purpose. The thematic maps can be digitized to permit integration of remote sensing data into geographic information systems (GIS) containing the thematic information.

c. Socio-economic maps;
Political units, transportation network, population distribution, agricultural and industrial census, tax or land price, and so on, are important factors for remote sensing applications and GIS.

Table 6.9.1 summarizes the required maps for remote sensing and GIS. Global change monitoring with the use of NOAA AVHRR, Nimbus CZCS or geosynchronous meteorological satellites is important for earth environmental analysis. In such cases, world maps which cover the whole earth may be necessary as a reference. Up to now, United Nations organizations such as UNESCO, UNEP, UNFAO etc. as well as NASA, NOAA and other international organizations, have produced various world maps.

Table 6.9.2 introduces several world-wide maps and map data available for the public. Some of these maps have been digitized in a digital database.

Table 6.9.3 shows the UN statistics for world topographic mapping as of 1987 with respect to the map scale and region. As seen in this table, topographic maps of 1:50,000 scale have been completed for only about 60 % of the total earth's land area, with especially low coverage in Africa, South America and Oceania. This is one reason why high resolution stereo image data are required for topographic mapping from space, and why radar imagery is attractive.

Table 6.9.1 Requried maps for remote sensing and GIS

map	objectives
Topo maps	- ground control point for geometric corrections - as a base map for interpretation - DEM generation for digital rectification / orthophoto mapping and 3-D view - slope and drainage for terrain analysis
Thematic maps	- sampling of training data for classification - integration of remote sensing and GIS
Socio-economic maps	- applications of remote sensing and GIS

Table 6.9.2 World topographic mapping

scale region	1:25,000	1:50,000	1:100,000	1:250,000
Africa	2.5	34.5	19.5	86.6
North America	37.0	71.1	37.1	99.2
South America	6.7	29.8	53.4	77.6
Europe	83.7	96.2	78.5	90.9
Asia	13.9	68.4	62.1	83.7
U.S.S.R.	100.0	100.0	100.0	100.0
Oceani	18.3	22.8	54.4	82.9
World	33.3	56.1	58.9	90.2

(%) U.N. 1987

6.10 Digital Terrain Data

Digital terrain data are topographic data, including ground height or elevation, slope (gradient and slope aspect), types of slope etc., which are called **DTM** (Digital Terrain Model) or **DEM** (Digital Elevation Model).

Terrain features can be expressed using the following four methods.

1) Contour Lines.
Usually elevations on a topographic map are represented as a group of contour lines with a discrete and constant contour interval.

2) Grid data.
For convenience of computer processing, a set of grid data with elevation are acquired from contour maps, aerial photographs or stereo satellite image data, as shown in Figure 6.10.1. Terrain data other than the grid data are interpolated from the surrounding grid data.

3) Random point data.
Terrain features are sometimes represented by a group of randomly located terrain data with three dimensional coordinates. For computer processing, random point data are converted to triangulated irregular network (**TIN**) as shown in Figure 6.10.2. TIN has the advantage of easy control of point density according to the terrain feature, though it has the disadvantage of being time consuming in the random search for the terrain point.

4) Surface function.
Terrain surface can be expressed mathematically as a surface function, for example, a Spline function.

A DEM can be generated by the following two methods.

1) Survey and photogrammetry
A ground survey is implemented using a total station, with a function of digital output, giving a high accuracy over a comparatively narrow area. Aerial photogrammetry can be executed by a digital plotter with a function of automated image matching. The digital 3D coordinates will be automatically generated. Stereo remote sensing data from space will be a powerful tool to produce 1:50,000 topographic maps in the near future.

2) DTM generation from contour maps
Contour lines are measured by a tablet digitizer manually, or by a scanner automatically or semi-automatically, to generate the DEM.

The DEM is used for generating a digital orthophotomap and a 3-D view as well, for terrain analysis in geomorphology and geological studies.

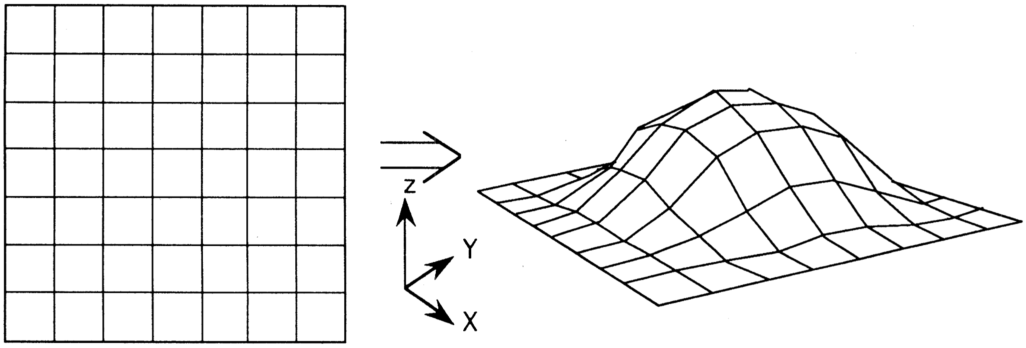


Figure 6.10.1 Mesh type

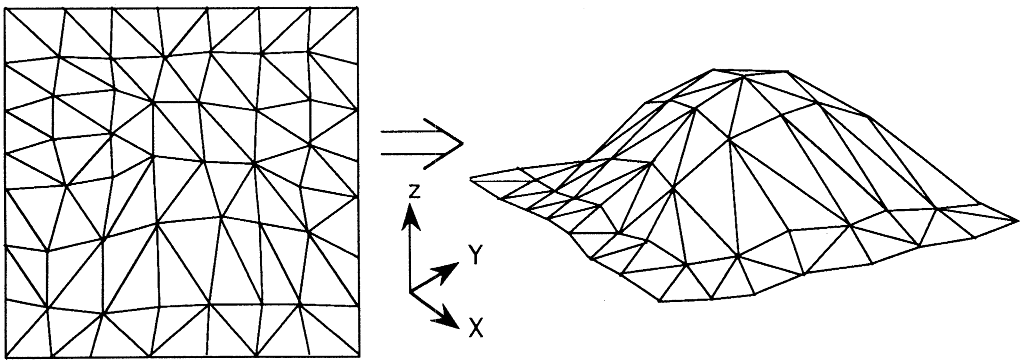


Figure 6.10.2 TIN type

6.11 Media for Data Recording, Storage and Distribution

Generally satellite data received at a ground station are recorded in real time into HDDT (high density digital tape) with 14 or 28 tracks. Depending on the requests, HDDT data will be transferred to **CCT** (computer compatible tape) with 9 tracks and/or other media for distribution. Recently optical disks for examples, **WORM** (write once read many), **MO** disk (magneto-optical disk with erasable function) and **CD-ROM** (compact disk - read only memory) are becoming popular.

These media are characterized by the following factors.

a. Memory capacity: total memory in byte
b. Cost: cost of media, reader and unit data volume (cost per 1 MB)
c. Compatibility: for data formats and computer systems
d. Portability: size and weight e. Durability: years of life

The type of media should be selected depending on the purpose, in consideration of the above items. Table 6.11.1 shows the characteristics of major media used in remote sensing.

For use in data centers the factors of data storage, portability, cost and durability are more important than compatibility. Recently DAT (digital audio tape) or 8 mm cartridge tape is replacing HDDT and CCT because of its compact size.

For distribution to public users, compatibility is most important, which makes CCT and floppy disk more popular. CD-ROM is very convenient and also low cost as mass media, similar to a music record disk. Optical disks such as MO and WORM are very attractive, though standardization and compatibility are not yet fully implemented. However the optical disk has the big advantages of low cost of both media and driver, and a large memory capacity, especially as a large auxiliary supplementary memory for personal computers or work stations.

Table 6.11.1 Characteristics of data storage/distribution media

Media	Capacity	Media price	Media cost	Compatibility	Portability
HDDT	7-100 GB	400 - 1000 $	1 - 6 cent/MB	×	×
Magnetic tape	0.15 GB	27 $	18 cent/MB	○	×
8mm cartridge tape	2.5 GB	20 $	0.3 cent/MB	○	○
DAT	1.3 GB	35 $	2 cent/MB	○	○
Streamer tape	0.15 GB	10,000 $	23 cent/MB	△	○
Optical tape	1000 GB	0.7 $	1 cent/MB	×	×
5.25 inch floppy disk	1.2 MB	1.3 $	60 cent/MB	○	△
3.5 inch floppy disk	1.2 - 4 MB	200 $	1 $/MB	○	○
5.25 inch MO disk	0.65 GB	47 $	30 cent/MB	△	○
3.5 inch MO disk	0.128 GB	130 $	37 cent/MB	△	○
5.25 inch WORM disk	0.8 GB	8 $	16 cent/MB	×	○
CD - ROM	0.54 MB	27 $	1.5 cent/MB	○	○

(Spec. and price are referred to market information as of 1991.)

6.12 Satellite Data Transmission and Reception

Transmitted data from remote sensing satellites involve not only image data but also **telemetry data** including temperature, electric voltage and electric current of various onboard equipment. Such data are usually transmitted as a digital signal in the form of **PCM** (pulse code modulation) with a binary pulse because the digital signal has the advantages of being noise proof, requiring less electric power and having available narrow radio bands. As the data volume or rate of transmission is very high, high frequency bands, such as S band or X band ranging from several GHz to several tens of GHz, are used to achieve the high rate of transmission.

These data are generally received by direct reception at a ground station. However this direct method is limited to reception only when the satellite is in view, nominally several degrees over the horizon, but usually above the horizons will suffice.

There are two methods used to record the satellite data at other areas outside the look angle; these are **MDR** (mission data recorder) and **TDRS** (tracking and data relay satellite).

MDR can record other data from areas other than the covering area of the ground station, and replay the data when the satellite flies over the ground station. For examples, NOAA, SPOT, JERS-1 etc. have the MDR system.

TDRS's have been launched by NASA over the equator at 41° W and 171° W , which can cover the whole of the earth tracking a lower altitude satellite and relaying the data to the ground station, located at White Sands, United States, as shown in Figure 2.12.1.

Landsat 4 and 5 are linked to TDRS. Table 6.12.1 shows the reception method for areas outside those covered by receiving stations.

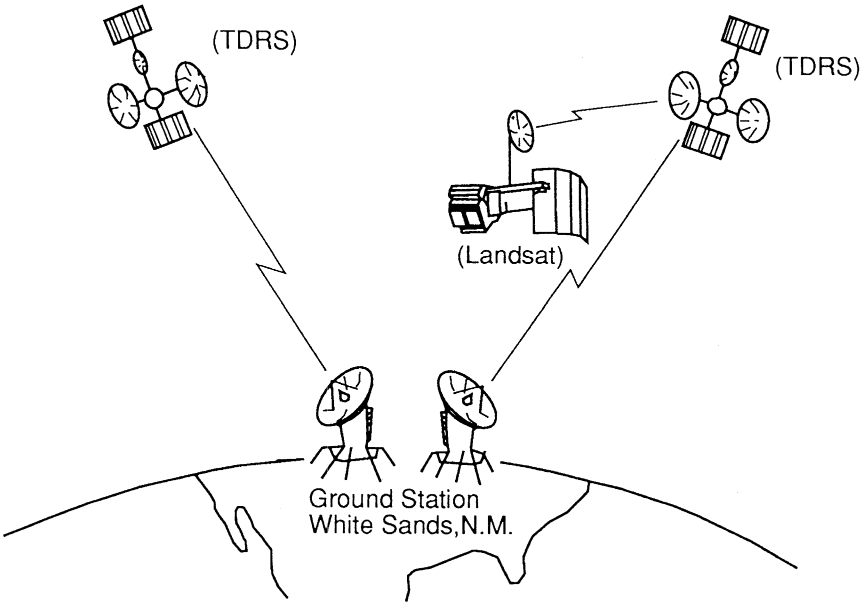


Figure 6.12.1 Conceptual figure of TDRS

Table 6.12.1 Receiving method for areas not collected by a receiving station

method	main satellite
MDR	SPOT, NOAA, JERS -1
TDRS	Landsat (4, 5)
unable to recieve	MOS - 1, ERS - 1

6.13 Retrieval of Remote Sensing Data

Data received by remote sensing satellites are normally purchased or made available at the operating space agencies, receiving stations or data distribution centers. Appendix Table 4 shows the main data distributors in the world. Searching for a satellite scene from a number of scenes is so complicated that retrieval systems with key words of satellite name, sensor, observed data, path and row number, cloud coverage etc. are made available for users.

In addition to such retrieving systems, which have been developed by each center, a comprehensive and international directory system being developed by the **CEOS** (Committee on Earth Observation Satellite). **CEOS-PID** (prototype international directory) is a world wide database, which is based on the master directory developed by NASA. This is a **directory database** to indicate what kind of satellite data are available at which center. Some data can be directly accessible on line to the **data inventory** of the center of interest.

Figure 6.13.1 shows the main menu of CEOS-PID. At present CEOS-PID has an international network, as shown in Figure 6.13.2. The users can utilize CEOS-PID by telephone line from any node of the network.

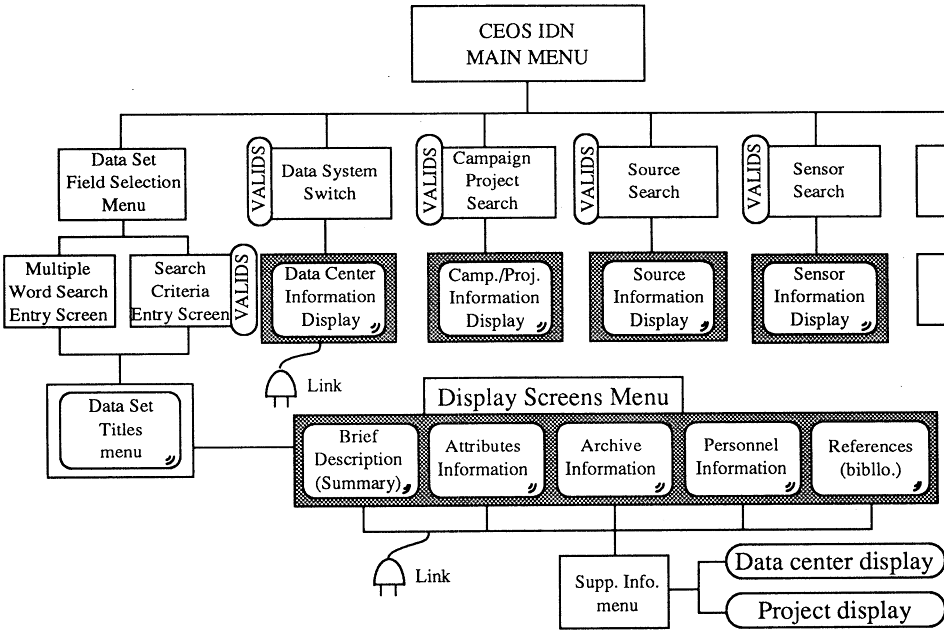


Fig. 6.13.1 Main Menu of CEOS IDN

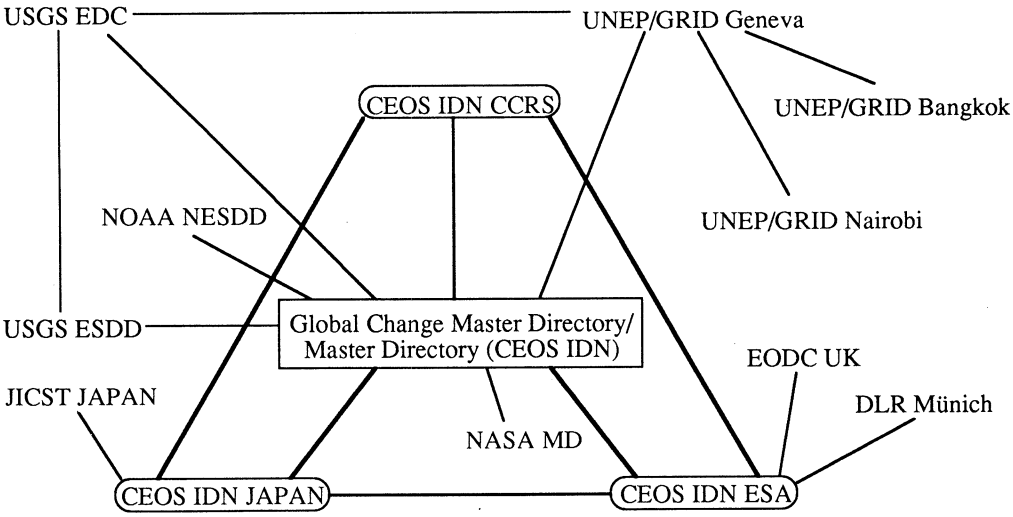


Fig. 6.13.2 International Network of CEOS IDN (Acronyms are explained in the Appendix)