Overview of First Phase of AVIRIS-NG Airborne Hyperspectral Science Campaign over India

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1. Scientific Rationale

Imaging Spectroscopy or Hyperspectral sensing (HSS) of Earth's land and ocean environments is based on the principles of spectroscopy either reflectance or emission spectroscopy over shortwave (0.3 to 3 μm) and longwave (5 – 50 μm) spectrum. Interaction of energy with the molecular and structure of surface materials results into characteristic or diagnostic absorption or emission features in the reflectance or emittance spectra. These diagnostic features occur due to changes in energy state of molecules as a function of electronic or vibrational transitions. The former occurs predominantly at shorter wavelengths due to changes in energy state of electrons bound to atoms or molecules or lattices. The latter occurs generally in longer wavelength due to stretches and bendings where overtones occur at sums or multiples of the fundamental vibration frequencies. HSS refers to 100 - 200 spectral bands generally in continuum with relatively narrow band interval (5 – 10 nm) in contrast to Multi-Spectral Sensing (MSS) that refers usually to 5 – 10 discrete wide bands with bandwidths about 50 – 400 nm. The advantages of reflectance HSS over MSS are : (i) the former can detect more materials or surface types such as minerals, rocks, vegetation, snow, (ii) relates directly to surface chemistry and (iii) can estimate the abundance of material present. This greater information content enables new methods for detection, characterization and quantification in a broad range of Earth system environments. The ability to develop HSS instrument is only recently enabled by technologies of the 21st Century. For high uniformity spectroscopy, the grating-based spectral dispersion approach as distinct advantages in comparison to the wedge-filter technological approach. Handheld field spectrometers are generally useful for ground-based survey. However, they provides only point target spectra and not the continuous spatial coverage over large areas required for many local, regional research and applications. Several imaging HSS instruments such as micro-hyperspec, nano-hyperspec and snapshot are available for hyperspectral imaging to provide data with centimeter spatial resolution from airborne (e,g, Aeroplane, Robotic UAV, Drones etc.) and ground-based platforms. The satellite-based HSS mission such as EO-1 Hyperion of NASA provided reasonably good datasets sampled around the globe, including India, but Hyperion suffers from low Signal-to-Noise Ratio (SNR). Nevertheless, potential applicability of HSS data from EO-1 Hyperion over India haave been demonstrated for agriculture (e,g. mustard crop disease), geology (e,g. Dongargarh, Rajasthan) by Bhattacharya and Chattopadhyay (2013), Dutta et al (2006), Bhattacharya et al (2012). In addition, several ground-based studies in India by Ramakrishnan and Bharti (2015), Sahoo et al (2015), Das et al (2015) using ground-based field spectrometers proved the potential advantages of using HSS data for crops, soils, geology etc. The applicability of HSS has already been shown for coastal-ocean chemistry, snow and glacier, coral reef and cloud microphysical characterization. The hyperspectral science initiative is also included in the "Big Data Initiatives" of Department of Science and Technology (DST), Govt. of India. Keeping the future applicability potential in tandem with the development of advanced technology, the ISRO-NASA joint airborne hyperspectral science campaign over India was begun in 2015.

2. Objectives

The broad objectives of ISRO-NASA hyperspectral programme are :

- To harness the benefits of unique and advanced remote sensing measurements for society by bringing together important talents and expertise in instrumentation, science and applications of both ISRO and NASA
- To jointly develop advanced science understanding, models, algorithms and techniques through knowledge sharing and to open up new avenues of collaboration.
- To provide the required precursor ground truth data and science and application research demonstrations for present and future ISRO space imaging spectrometer missions.

3. Airborne Hyperspectral Instrument and Study sites

The Airborne Visible and InfraRed Imaging Spectrometer – Next Generation (AVIRIS-NG), of JPL (Jet Propulsion Laboratory), NASA, has been used for the ISRO-NASA airborne campaign on-board an ISRO B200 aircraft. There are about 430 narrow continuous spectral bands in VNIR and SWIR regions in the range of 380 – 2510 nm at 5 nm interval with high SNR (>2000 @ 600 nm and >1000 @ 2200 nm) with accuracy of 95% having FOV of 34 deg and IFOV of 1 mrad. Ground Sampling Distance (GSD) vis-à-vis pixel resolution varies from 4 – 8m for flight altitude of 4 – 8 km for a swath of 4-6 km. The science themes are spread over eight broad areas with a total 57 sites in Priority 1 and 25 sites in Priority 2 scheduled for imaging by AVIRIS-NG based on proposals by scientists from ISRO centres, universities, IITs. The science themes and number of Phase - 1 campaign sites are given in Table 1.

Table 1. Science themes and study sites for Phase - 1 campaign

Sr. no.	Broad science themes	Sub-themes	No. of study sites
1.	Agriculture and Ecosystem	Crop, Soil, Mangrove, Wetland	21
2.	Geology		11
3.	Ocean & coastal	Coastal zone, biological oceanography, coral reef	11
4.	Rivers and water quality		5
5.	Urban		2
6.	Snow and ice		2
7.	Atmosphere	Air quality, cloud microphysics	3
8.	Calibration and validation		2

The geographical distribution of sites and their False Color Composites (FCCs) from IRS (Indian Remote Sensing) satellite sensors with flight paths are shown in Figure 1 and Figure 2, respectively.

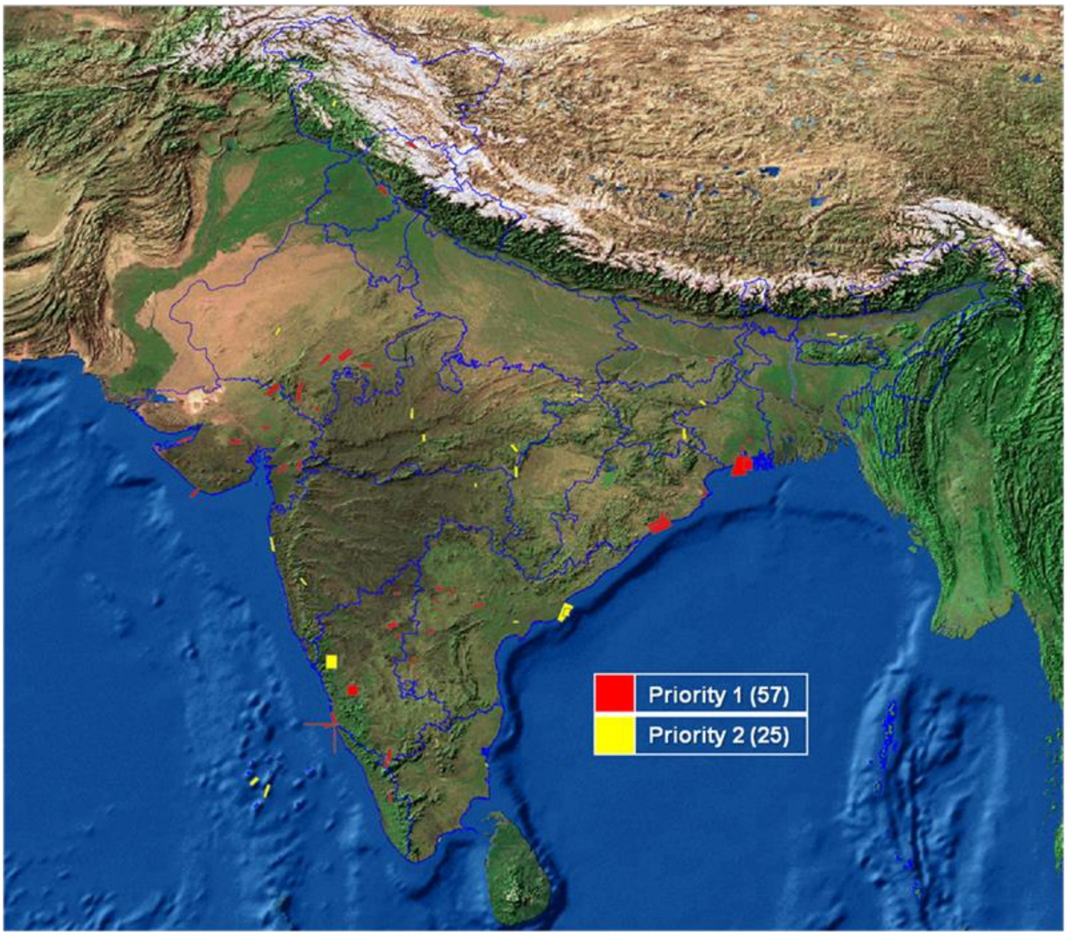

Figure 1. Geographical distribution of AVIRIS-NG science campaign sites

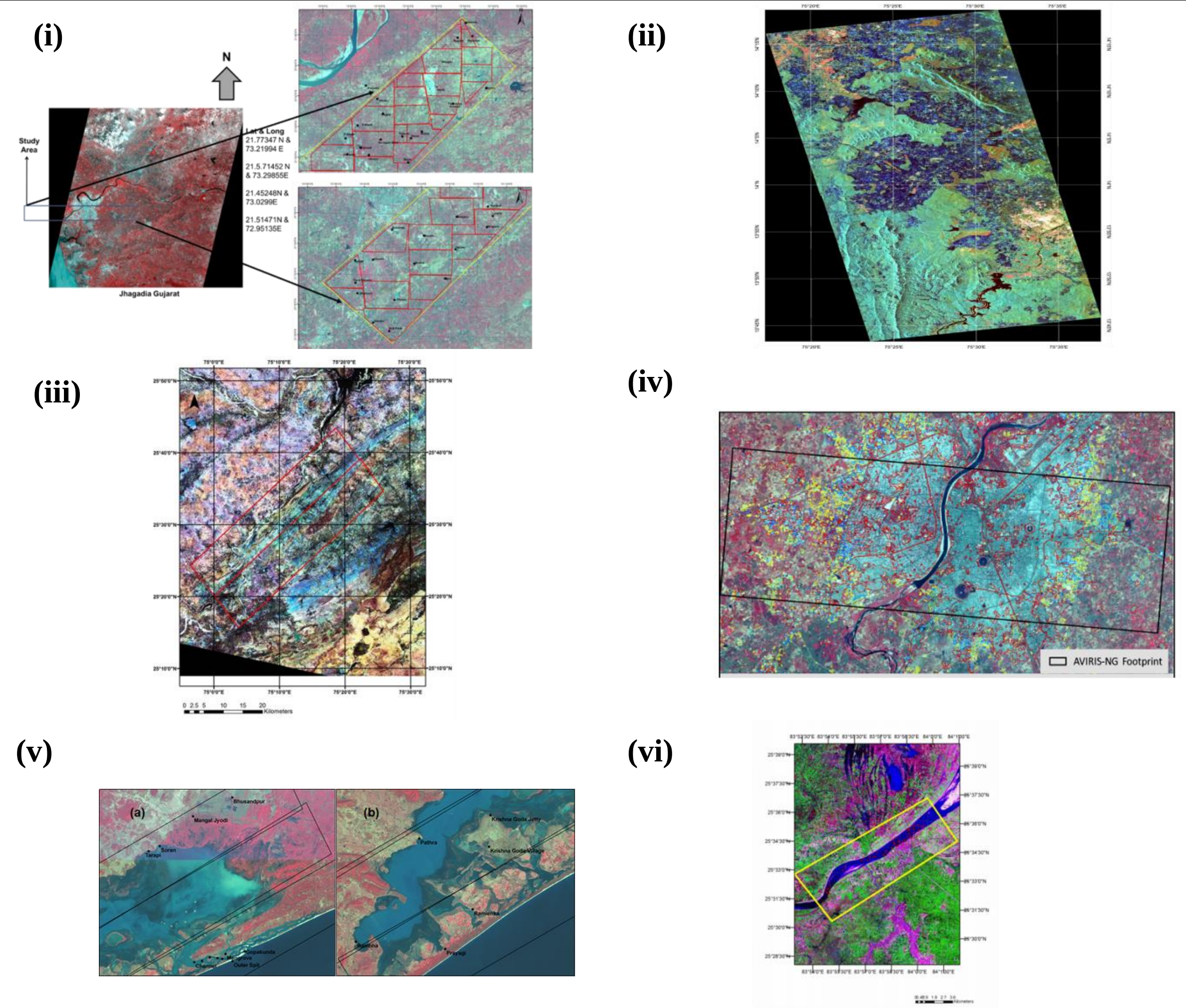

Figure 2. Examples of sites and flight paths for (i) agriculture (ii) forest (iii) geology (iv) urban and air quality (v) coastal and ocean and (vi) river and water quality

The photographs airborne campaign teams with B200 aircraft and AVIRIS-NG instrument are shown in Figure 3

Figure 3. Airborne campaign team and science field campaign team with B200 aircraft and AVIRIS-NG instrument

4. Campaign Coordination, Execution and Ground-Truth Data Collection

First pre-campaign science meeting took place on 30 September 2015 at Space Applications Centre, Ahmedabad among the interested researchers to organize theme-wise field sampling plans, sampling points, time of samplings, availability of filed spectrometers, sun photometers for atmospheric measurements, and other field instruments. The types and protocols of biochemical, geochemical analysis, laboratory-based spectroscopy of field samples have been planned. Site-wise teams were formed for each theme by pooling the participating researchers from SAC, NRSC, IIRS, RRSCs, IIT, ICAR, Universities keeping in view of smooth transition of field instruments from one team to another. Two rounds of cross-calibration of different sets of field instruments and hands-on were arranged at SAC. The IRS RS-2, LISS IV and RISAT-1 FRS-1 data have been arranged near coincident to date of flights for highly dynamic sites (e.g. agriculture). The airborne acquisition campaign with AVIRIS-N started on 19 December 2015 and continued through 8 March 2016. First data sets were acquired with a brief CAL-VAL campaign at Begumpet airport, Hyderabad to evaluate performance of AVIRIS-NG with respect to ground measured spectra. The final data set were acquired over the Gulf of Kutch in Gujarat. The flight campaign was organized from nine airport bases (Table 2) Ahmedabad, Udaipur, Bhubaneswar, Hyderabad, Mangalore, Coimbatore, Chandigarh, Patna, Kolkata. More than 200 people participated in the field campaigns corresponding to date of flight and flight path. An internet-based 'What's App' group was made for better on-site coordination for mobility of field teams to accommodate last-minute changes due to change in flight schedule depending on Air Traffic Control (ATC) clearances. High-resolution short-range weather forecast on cloud fraction from MOSDAC was provided to campaign coordination teams and field campaign teams for effective and efficient flight planning and field data collection.

Table 2. AVIRIS-NG Airborne hyperspectral Phase-1 Campaign diary

Serial No.	Airports (In chronological order as per flight schedule)	Duration	No. of sites	Area Imaged (km^2)
1.	Begumpet	16 to 21 December 2015 25 to 29 January 2016	12	2650
2.	Bhubaneswar	22 to 28 December 2015	6	3780
3.	Mangalore	29 December 2015 to 2 January 2016	5	3491
4.	Coimbatore	3 to 8 January 2016	5	1416
Phase inspection of aircraft				
5.	Udaipur	31 January to 5 February 2016	8	3697
6.	Ahmedabad	6 to 16 February 2016 6 to 9 March 2016	10	2788
7.	Chandigarh	17 to 21 February 2016	4	835
8.	Patna	22 to 24 February 2016	3	396
9.	Kolkata	24 February to 6 March 2016	4	3787
Total no. days = 84, Total area imaged = 22840 sq. Km over 57 sites				

Exceptional volumes of high quality field spectra and associated field data were collected coincident with airborne measurements. Examples of flight paths, field photographs, field-based spectroscopic measurement over different targets are shown in Figure 4, 5, 6, respectively.

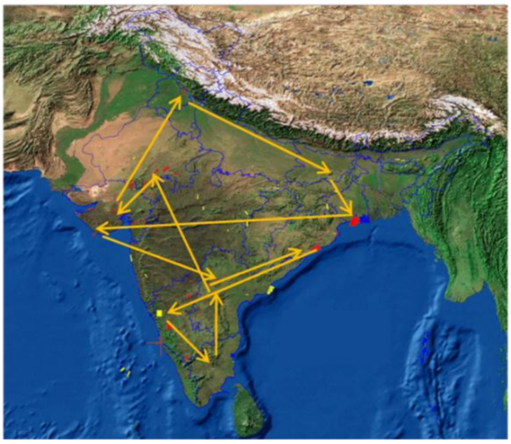

Figure 4. Flight paths of Phase-1 AVIRIS-NG airborne campaign

Figure 5. Field photographs of Ground-truth campaigns

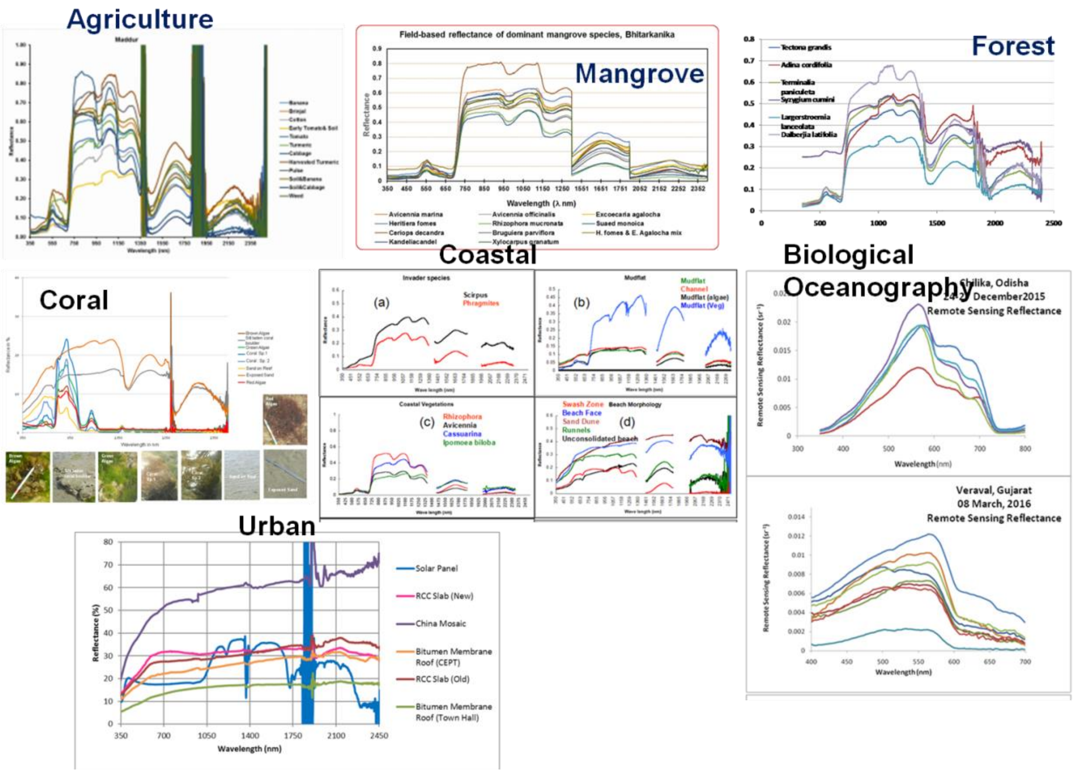

Figure 6. Examples of field-based hyperspectral signatures over different thematic targets

Laboratory-based chemical analysis were also carried out on soil, vegetation, rock and water samples collected during field campaigns. These have been used along with AVIRIS-NG data to demonstrate the utility imaging spectroscopy measurements, to test and develop new algorithms, tools, techniques, enhanced science understanding and also to define future space-based satellite mission.

5. Product levels

Example imaging spectroscopy data sets acquired by AVIRIS-NG are shown as 3D data cubes in the Figure 7. The sample natural color composites in 2D frame are shown in Figure 8.

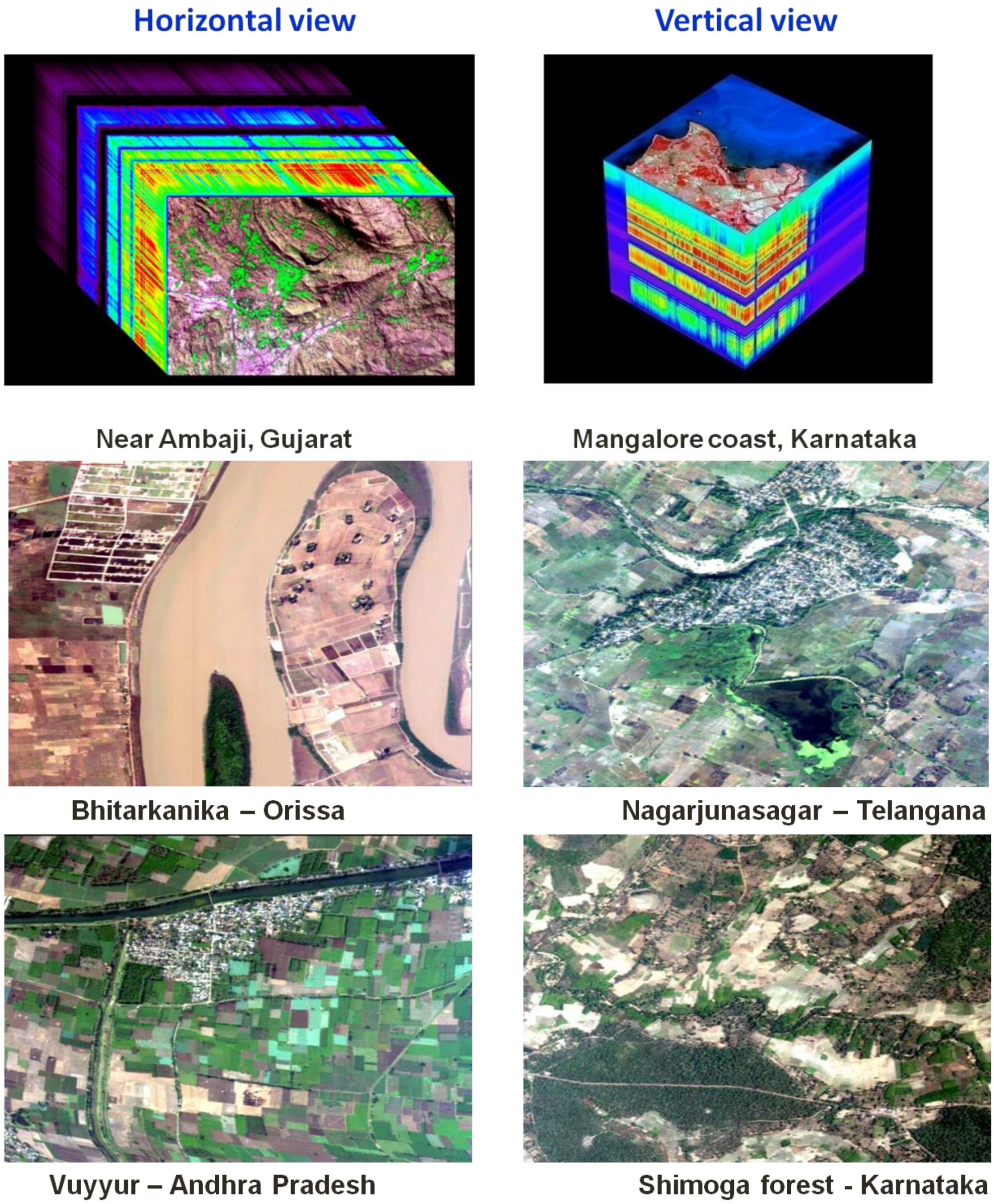

Figure 7 to 8. Examples of 3D data cubes and NCC images from AVIRIS-NG

Three levels of products such as L0, L1 and L2 have been targeted to be obtained from AVIRIS-NG data. The L0 and L1 data represent raw data, calibrated and ortho-rectified top-of-radiance (TOA), respectively which were generated on-board the aircraft. An example of L1 data product is shown in Figure 4. The L2 data represent surface reflectance products in all the bands after atmospheric correction. Two types of prototype models such as point-based and pixel-based have been developed. The former is useful for a sub-scene where atmosphere is assumed spatially invariant and point-measured aerosol optical depth and water vapour can be used for generating surface reflectance. Pixel-based approach first derives atmospheric water vapour and aerosol optical depth pixel-by-pixel from TOA radiance itself and serve as inputs to atmospheric correction models.

Table 1. Product type, definition and correction levels

Product type	**Product definition**	**Data content**
Level - 0	Raw	Raw data as captured by the sensor + GLT, IGM & LOC Files
Level - 1	Calibrated Radiances	Radiance Image Cube + GLT, IGM & LOC Files
Level - 2	Atmospherically-corrected surface reflectance	Surface Reflectance Image Cube + GLT, IGM & LOC Files

6. Data archival and dissemination

The AVIRIS-NG data have been archived in VEDAS (vedas.gov.in) of SAC after obtaining due clearances of collected data from Ministry of Defence (MoD), Govt. of India and further processing by JPL and SAC. The different facilities of VEDAS portal and data flow mechanism are shown in Figure 9. About 230 AVIRIS-NG scenes with data storage of 1.5 TB collected over 57 sites in the 1st Phase of campaign have been archived in VEDAS. In addition to that, ground-truth data and field campaign reports are also archived in VEDAS. Data are being disseminated to interested researchers of different Indian Academia based on certain guidelines.

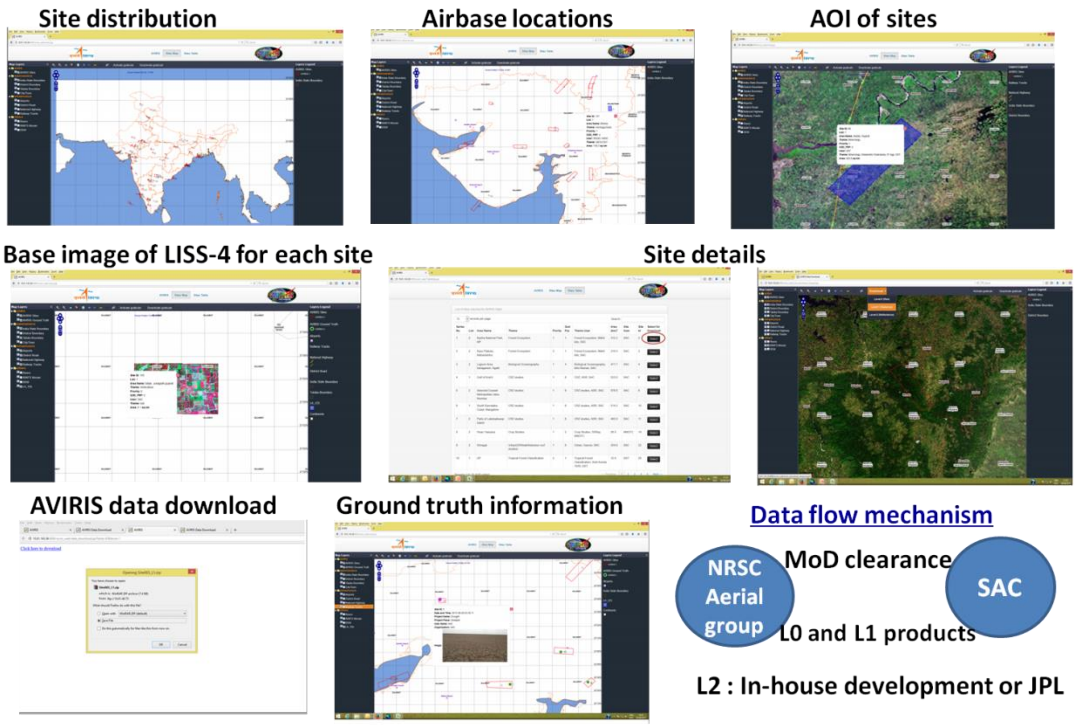

Figure 9. AVIRIS-NG data archival facility and data flow mechanism

7. Capacity Building : Announcement of Opportunity (AO)

Human resources will be developed among different research agencies and academia to develop the expertise on the use of imaging spectroscopy measurements. To that end, an Announcement of Opportunity (AO) for proposals has been released to Indian research agencies. About thirty-five (35) such proposals have been short-listed based on the technical merits and innovativeness. PhD work is being encouraged through these proposals. First course of training has been given to AO Principal Investigators (PIs) and students involved in the research. The AVIRIS-NG data have been shared to all Indian AO PIs through VEDAS. NASA has also announced AO for US researchers and the received proposals are in the process of selection.

8. Major Achievements

The highlights of major achievements are given below :

- Prototype ATCORR algorithms for land & water have been developed and evaluated
- Processing module has been developed for pixel-based Integrated Band Depth
- (IBD), First-order derivative, to determine hidden or children peaks of pigment absorption through spectral deconvolution
- Processing module developed for field spectroscopy data (Savitzsky-Golay filtering, absorption band centre, FWHM & depth)

- Prototype of creating, visualization of spectral library and improved classification through genetic algorithm
- Cal-Val experiments have been carried out for AVIRIS-NG TOA radiance and surface refectances at Desalpar, Gujarat and GMDC ground, Ahmedabad
- Different sensitive band regions could be identified for improved discrimination of forest species, crop types, disease detection, canopy and soil water stresses, soil types, land uses, coral reef macro-algae, mineral, coastal vegetation, urban roof types have been carried out
- Retrieval schemes have been developed for determination of crop chlorophylls, ocean chlorophyll, CDOM concentration, suspended sediments and coastal bathymetry, water turbidity parameters and validated
- Retrieval schemes of different atmospheric parameters such as aerosol optical depth, water vapour, atmospheric CO2, cloud-microphysical parameters have been developed and validated
- Snow-grain size characterization and lichen presence in alpine areas in Western Himalayan region have been ascertained with AVIRIS-NG spectra.

Theme-wise achievements are elaborated given in subsequent sections.

The future plans include (i) conducting a second phase of airborne campaign with AVIRIS-NG data with repeat observations over 57 sites and imaging over additional sites to develop sound spectral library and digital spectroscopy catalogue (ii) to carry out exhaustive validation (iii) holding international workshops. The experience with AVIRIS-NG data will be useful to generate operational products from future space imaging spectrometer payloads.

9. Linkage to Key Societal benefit areas

The end-use applications of thematic investigations would support important key societal benefit areas such as :

A. Food security : Precision farming, crop insurance, soil health assessment
B. Mineral exploration : Fertilizer prospecting, Identifying new mining areas, mineral abundance mapping, hydrothermal alteration
C. Water and air quality assessment for river, lakes, ponds, canals and industrial plume dispersal
D. Mapping medicinally important coral macrophytes, medicinally important plants and commercially important forest tree species
E. Urban development and planning for climate change mitigation
F. Improved science understanding bio-geochemical cycle for climate change.

Acknowledgements

The authors are grateful to Director, Space Applications Centre, ISRO, Ahmedabad and Director, National Remote Sensing Centre, ISRO, Hyderabad for their constant support and encouragement to carry out this airborne campaign in a time-bound manner. The AVIRIS-NG contribution has been supported by NASA and the Jet Propulsion Laboratory, California Institute of Technology.

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