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Naval EarthMap Observer (NEMO)
Hyperspectral Remote Sensing Program

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Abstract

The NEMO hyperspectral remote sensing program will provide unclassified, space-based hyperspectral passive imagery at moderate resolution that offers substantial potential for direct use by Naval forces and the Civil Sector. NEMO merges Navy-developed technology with commercial technology and provides a space-qualified hyperspectral imager with the coverage and sensitivity required to collect broad-area synoptic imagery over land and ocean on a global basis. NEMO is a joint government and industry effort between the Naval Research Laboratory (NRL) and its industry partner Space Technology Development Corporation (STDC). NEMO is sponsored by the Office of Naval Research (ONR) and DARPA's Joint Dual-Use Application Program (JDUAP). NRL provides the design and integration of the NEMO sensor imaging payload with a commercial satellite bus as well as bus modifications, the on-board imaging processor, feature extraction and data compression software, and systems engineering. In addition, data products and algorithms are being developed by the Navy. STDC and its industry partners will provide the commercial satellite bus, launch services, commercial processing facilities, and long-term flight operations.

The NEMO program is currently in the hardware fabrication stage, concentrating on the manufacture and testing of flight hardware. NEMO will carry the Coastal Ocean imaging Spectrometer (COIS) which will provide images of littoral regions with 210 spectral channels over a bandpass of 0.4 to 2.5 μm. Since ocean environments have reflectances typically less than 5%, this system requires a very high signal-to-noise ratio (SNR). COIS will sample over a 30 km swath width with a 60 m Ground Sample Distance (GSD) with the ability to go to a 30 m GSD by utilizing the systems attitude control system to "nod" (i.e., use ground motion compensation to slow down the ground track of the field of view). Also included in the payload is a co-registered 5 m Panchromatic Imager (PIC) to provide simultaneous high spatial resolution imagery. A sun-synchronous circular orbit of 605 km allows continuous repeat coverage of the whole earth. One unique aspect of NEMO is an on board processing system, a feature extraction and data compression software package developed by NRL called the Optical Real-Time Spectral Identification System (ORASIS™). ORASIS™ employs a parallel, adaptive hyperspectral method for real time scene characterization, data reduction, background suppression, and target recognition. The use of ORASIS™ is essential for management of the massive amounts of data expected from the NEMO Hyperspectral Imagery (HSI) system, and for developing Naval products.

The combined HSI and panchromatic images will provide critical phenomenology to aid in the operation of Naval systems in the littoral environment. The imagery can also satisfy a number of commercial and science community requirements for moderate spatial and high spectral resolution remote sensing data over land and water. Specific areas of interest for the Navy include bathymetry, water clarity, bottom type, atmospheric visibility, bioluminescence potential, beach characterization, underwater hazards, total column atmospheric water vapor, and detection and mapping of subvisible cirrus. These data support requirements for Joint Strike and Joint Littoral warfare, particularly for environmental characterization of the littoral ocean. Demonstrations of timely downlinks of near real-time data to the warfighter are also being formulated. The launch date for NEMO has not been set yet. The commercial partner continues to seek necessary commercial capital to complete the program.

1. Background

The Navy is in the midst of a fundamental shift away from open ocean deep water operations to joint littoral warfare. To support that effort, the Navy and Marine Corps need more precise information in denied areas regarding shallow water bathymetry, bottom type composition, detection of underwater hazards, water clarity, and visibility[1]. Visible radiation is part of the electromagnetic spectrum that penetrates the water, and passive optical systems can provide these products from space.

To address the problems of the coastal ocean, NRL scientists have been working since 1990 using the Airborne Visible/InfraRed Imaging Spectrometer (AVIRIS)[2,3] which is operated by the Jet Propulsion Laboratory and flown on an ER-2 operated by NASA. AVIRIS data provides 20 m spatial resolution and 220 spectral bands covering a 0.4 to 2.4 μm spectral range at 10 nm resolution. In a collaborative effort with the University of South Florida, NRL has demonstrated the use of AVIRIS data to separate the chlorophyll signal from bottom reflectance in the clear waters of Lake Tahoe[4] and the turbid waters offshore from Tampa Bay[5]. In addition, spectral signals from resuspended sediments and dissolved organic matter have been interpreted for the Tampa AVIRIS images[5,6], and for suspended sediments and kelp beds for AVIRIS images of the San Pedro Channel[7]. These results lead to a general semi-analytical model for decomposition of the spectral signatures[8,9].

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Similar progress has been made on the land applications of imaging spectrometer data since the value of that data was first highlighted in an article in *Science* in 1985[10]. Primarily using AVIRIS data, applications have been developed for the retrieval of atmospheric properties and for assessing crop status, environmental quality, and mineral exploration (e.g., *Remote Sensing of the Environment*, Vol. 44(2-3), Special Issue on Airborne Imaging Spectrometry). In particular, mineral exploration has become a hot topic. Several companies now provide services interpreting AVIRIS or other aircraft hyperspectral data for mineral exploration. NEMO will provide the first data from space suitable for this application.

Multispectral imagers, such as Landsat and SeaWiFS, do not have sufficient spectral bands to resolve the complex spectral signatures in the coastal ocean or the spectral signatures used for mineral exploration. Imaging spectrometers do resolve those signatures and are an ideal tool to fill these requirements, but they have not been used to date because of cost and the demands of processing the data. Both these problems have been overcome in recent years.

Multispectral sensors image several wide discontiguous spectral bands (usually 3 to 5); hyperspectral sensors image at least 60, 10 nm wide contiguous spectral bands. As defined by Goetz et al[10] each pixel within a hyperspectral image contains a continuous spectrum used to identify materials by their reflectance or emissivity. This allows identification of components within a scene (i.e., types of minerals, trees, crop health, bathymetry, composition) versus multispectral, which can only identify major features of a scene (i.e., rocks, trees, crops, water). Figure 1 gives a description of the imaging spectrometry concept.

2. Navy Program Objectives

For the Navy, the central focus of the NEMO program is to develop and fly a satellite-borne earth-imaging HSI system to provide HSI data and to process the data to meet Naval and commercial requirements. The mission objectives are as follows:

- Demonstrate use of hyperspectral imagery for the characterization of the littoral battlespace environment and littoral model development.

- Demonstrate automated, on-board processing, analysis, and feature extraction using ORASIS™

- Demonstrate the value of hyperspectral data for DoD operations and commercial applications.

- Demonstrate support to the warfighter with real-time tactical downlink of hyperspectral end products directly from the spacecraft to the field.

2.1 Naval Requirements. NEMO meets the unique requirements of Naval Forces by imaging the littoral regions of the world in 210 spectral bands over a 0.4 to 2.5 μm bandpass with a very high SNR. NEMO has the goal of characterizing the dynamics of the littoral environment through the use of hyperspectral imagery and the development of coupled physical and bio-optical

models of the littoral ocean. The collected images provide critical phenomenology to model the littoral environment. Specific areas of study for the Navy include water clarity, bathymetry, underwater hazards, currents, oil slicks, bottom type, atmospheric visibility, tides, bioluminescence potential, beach characterization, atmospheric water vapor, and subvisible cirrus along with terrestrial images of vegetation and soil. These data support identified requirements for Joint Strike and Joint Littoral warfare, particularly for environmental characterization of the littoral ocean and intelligent preparation of the battlespace for amphibious assault.

3. Commercial Program Objectives

Earth Search Sciences Inc. (ESSI) acquired Space Technology Development Company (STDC) and the commercial rights to the NEMO Program's hyperspectral satellite and data system. The current stated commercial program objectives are:

- Develop the next generation of HSI sensor.

- Develop improved data collection and processing to provide near real-time products from large quantities of data (includes use of the Navy's ORASIS™ software).

- Form a joint venture with one or more aerospace partners to complete the NEMO project and develop additional satellite based imaging systems.

- Aggressively exploit and market end-to-end hyperspectral data and products to domestic and international clients.

- Deploy ESSI's web-based TERRANET imagery delivery system.

- Develop a next generation of spaceborne hyperspectral instrument to replace NEMO at the end of its useful life.

4. NEMO Mission Description

The NEMO spacecraft will be launched into Low Earth Orbit (LEO). The spacecraft will be placed in a sun-synchronous, 97.81° inclination orbit at 605 km altitude with a 10:30 a.m. ascending equator crossing. This orbit will provide a 7 day repeat coverage ability to allow, at a minimum, weekly access to any point on the earth. The 10:30 a.m. orbital crossing ensures consistent image quality and minimal cloud cover. Table 1 provides a general overview of the NEMO program mission characteristics. The sensor complement flown on the NEMO spacecraft includes a Coastal Ocean Imaging Spectrometer (COIS) and a co-registered Panchromatic Imaging Camera (PIC). The primary challenges in the COIS design are the wide field of view (>2.5°) and the very high SNR, particularly near the blue end (0.4 μm) of the spectrum required for ocean imaging. NEMO also employs NRL's Optical Real-time Adaptive Spectral Identification System (ORASIS™), an automated end-to-end HSI data processing system that will significantly reduce the amount of data NEMO must transmit to the ground. Figure 2 shows the current NEMO sensor deck concept.
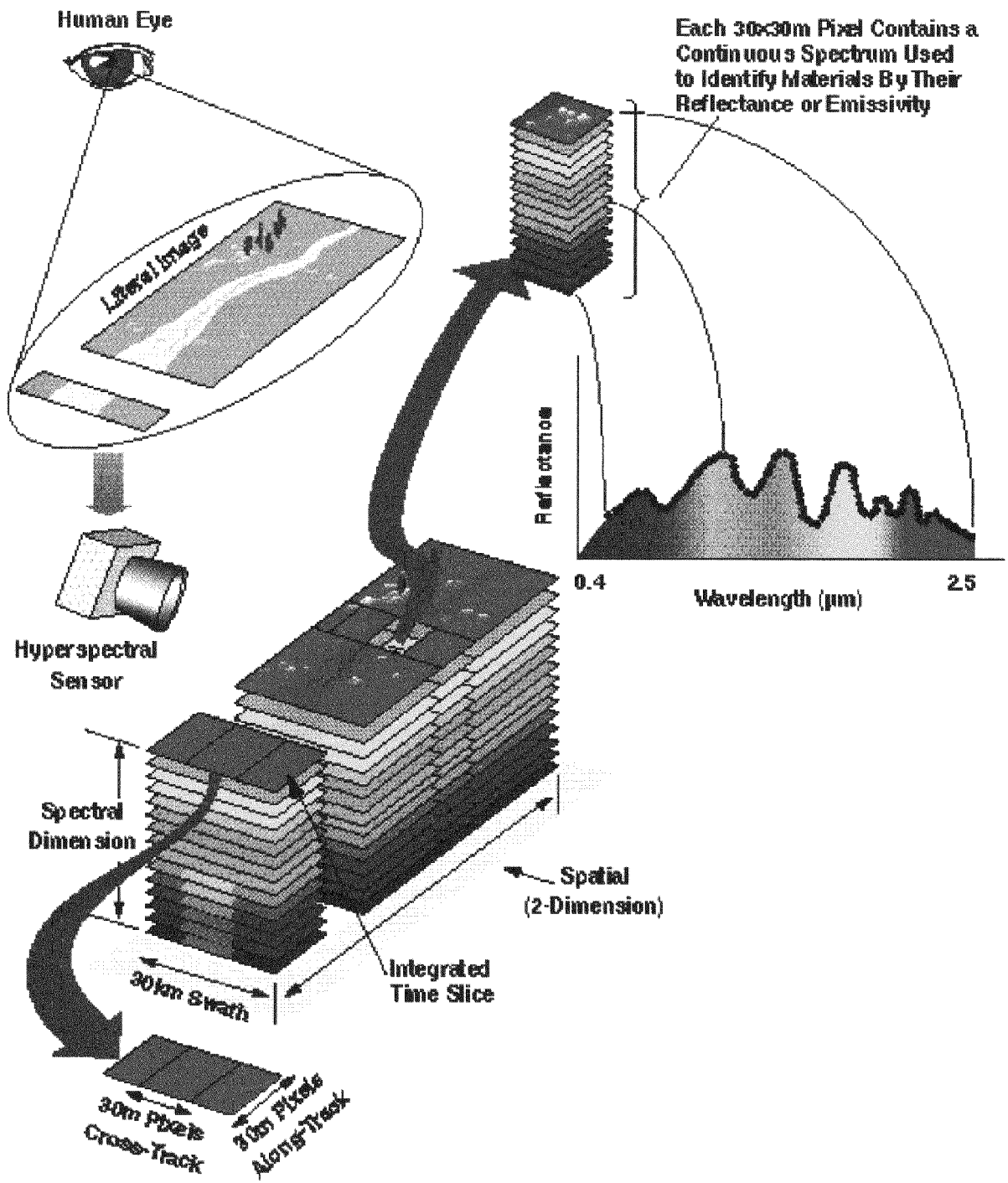
Figure 1. Imaging Spectrometry Concept

Table 1. Mission Characteristics

| Item	Parameter
Orbit	■ 605 km sun synchronous (97.81° inclination) ■ 10:30 am equatorial crossing (ascending)
Repeat Global Coverage	■ 7 day repeat, 2.5 day global average re-access
Spectral Range	■ 0.4 to 2.5 μm at 10 nm spectral resolution (210 bands)
Signal-to-Noise	■ >200 to 1 over 0.4 to 1.0 μm for a 5% reflectance target
Weight	■ 574 Kg
Power	■ 1,500 Watts
Lifetime	■ 3 year mission life ■ 5 year design life
Data Rates	■ 150 Mbps X-Band imagery and telemetry downlink ■ 1 Mbps S-Band imagery downlink for tactical demonstration ■ 2 kbps S-Band command uplink
Data	■ Maximum capability of ≈105 Gbytes/day
On-Board Processing	■ Real-Time feature extraction and classification with >10x data reduction using ORASIS™
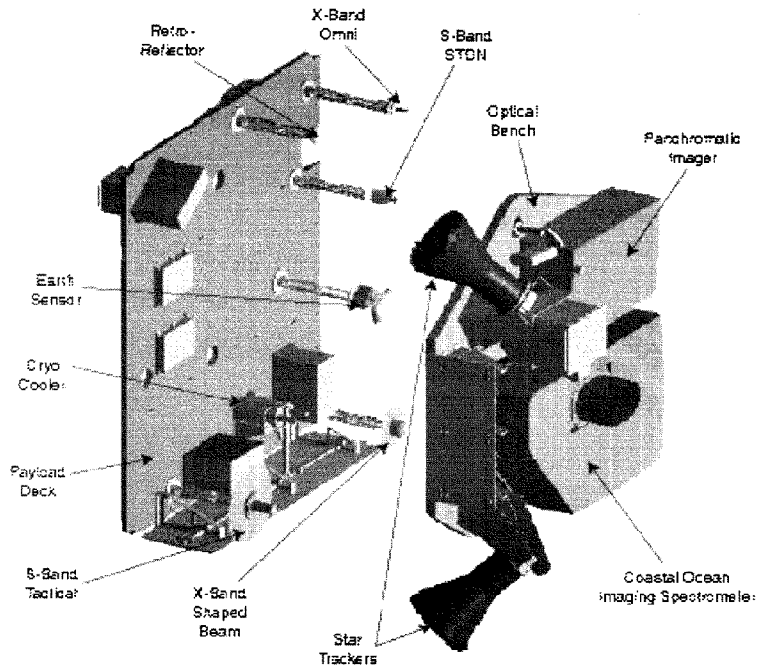
Figure 2. NEMO Sensor Deck Concept

Table 2. Sensor Systems Characteristics

	VNIR	SWIR	PIC
Ground Sample Distance (GSD)	30 m with 5:1 GMC 60 m with no GMC	30 m with 5:1 GMC 60 m with no GMC	5 m (with or without GMC)
Spectral Range	0.4 to 1.0 μm	1.0 to 2.5 μm	0.545 to 0.769 μm
Spectral Bands	60	150	1
Signal to Noise Ratio	>200 to 1 @ 5% Reflectance	>100 to 1 @ 30% Reflectance	>200 to 1 @ 30% Reflectance
Swath Width	30 km	30 km	30 km
Swath Length	200 km @ 30 m GSD continuous @ 60 m GSD	200 km @ 30 m GSD continuous @ 60 m GSD	Continuous
Field of View	2.86 degrees	2.86 degrees	2.86 degrees
Ground Swath Width	30 km	30 km	30 km
Aperature Diameter	15 cm	15 cm	16.4 cm
Focal Length	36 cm	36 cm	120 cm
F#	2.4	2.4	7.32
Pixel Size	18 μm	18 μm	10 μm
# of Pixels/Spectral Band	6	6	N/A
FPA Material	Si	MCT	Si
On-Orbit Sparing	1 for 1 Spare	1 for 1 Spare	1 for 1 Spare

4.1 Coastal Ocean Imaging Spectrometer (COIS). The present design of the COIS instrument employs a three-mirror-off-axis anastigmat (TMA), 12 cm aperture telescope and two spectrometers to image a 30 km wide ground swath at a 30 m GSD. Table 2 provides the characteristics of the HSI sensor system. The two spectrometers used in the COIS are:

The Visible Near Infrared (VNIR) spectrometer that disperses the 0.4 to 1.0 μm light into 60 spectral channels (10 nm wide) and onto the Focal Plane Array (FPA). This provides a resolution of 1.0 to 1.5% of the band and 60 spectral bins.

The Short-Wave Infrared (SWIR) spectrometer that disperses the 1.0 to 2.5 μm light into 150 spectral channels (10 nm wide) and onto the FPA. This provides a resolution of about 0.6% of the band and 150 spectral bins. To achieve high SNR performance, the SWIR requires active cooling by a cryocooler.

COIS provides very high SNR environmental products for imaging the low-reflectivity ocean surface. The NEMO sacecraft implements Ground Motion Compensation (GMC) sufficient to reduce the apparent ground speed by a factor of 5. This provides the required dwell time to give a similar high SNR at a GSD of 30 m. COIS is also capable of producing 60 m GSD, high SNR data products without GMC by using spatial binning of the hyperspectral FPAs. Figure 3 shows the baseline COIS optical design.

4.2 Panchromatic Imaging Camera (PIC). The PIC is a separate instrument that uses a similar off-axis telescope to simultaneously image the same 30 km swath as the COIS instrument onto a 6000 pixel long linear array to produce a panchromatic image in the 0.45 to 0.67 μm wavelength range at a 5 m GSD. The moderate COIS GSD matches the spatial scale of natural objects in the littoral zone, while the high resolution PIC provides simultaneous context and sharpening and supports commercial land imaging requirements. The 30 km ground swath of COIS and PIC spans the near-shore land, beach, and ocean. COIS and PIC use a single optical bench to minimize optical boresite drift. Table 2 provides the characteristics of the PIC sensor system and the sensor designs are described in a previous paper[12]. The COIS and PIC sensors are presently in fabrication by SAIC.

4.3 Optical Real-time Adaptive Spectral Identification System (ORASIS™). The NEMO program employs NRL's automated end-to-end HSI data processing system called ORASIS™. ORASIS™ offers automated and adaptive signature recognition capability, improving the operational efficiency to analyze both military and commercial data sets. It is important to note that while ORASIS™ is fully automated, it is also computationally intensive, requiring the NEMO satellite to have an on-board processor with multi-GigaFLOP capability.
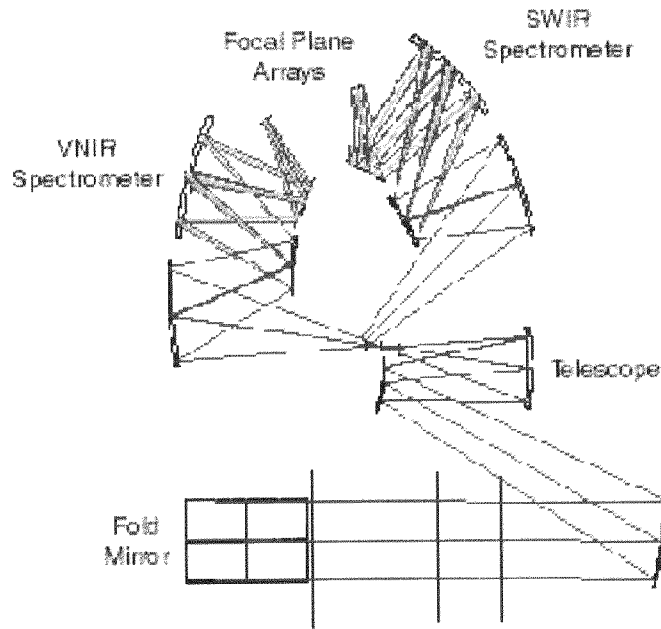
Figure 3. COIS Optical Design

ORASIS™ is a high-speed processing system that identifies the spectral signatures corresponding to physical objects in the scene without supervision or *a priori* knowledge. The approach is to analyze each spectra in the scene sequentially, discarding duplicate spectra, and working only with the unique spectra and the map of their location in the scene. Using convex set methods and orthogonal projection techniques each observed spectrum is then analyzed in terms of the set of vectors that represent the physically meaningful basis patterns that have combined to make the observed spectrum. Then matched filters (Filter Vectors) are created and used to demix the image[14,15].

ORASIS™ processing on board NEMO minimizes subsequent ground processing for data exploitation and maps of identified features, and enables the on-board production of data products. An important benefit of ORASIS™ processing is a greater than tenfold data compression (lossy), relieving hyperspectral data bottlenecks of on-board data storage and transmission to the ground. An early version of ORASIS™ was successfully flight demonstrated in a tactical environment in the 1996 COVERED LANTERN exercise, using hyperspectral images from a Pioneer Uncrewed Aerial Vehicle (UAV). This test proved ORASIS™ compression and detection capabilities.

For NEMO, ORASIS™ is implemented on the Imagery On-Board Processor (IOBP), an advanced high speed computer consisting of a highly parallel array of digital signal processors, capable of sustaining 2.5 GigaFLOPS. The ORASIS™ algorithm and the radiation tolerant IOBP allow the first demonstration of real-time processing of hyperspectral data in space. The NEMO on-board implementation of ORASIS™ is described in detail in a previously published paper.[15]

ORASIS™ will also be used under the NEMO program as the basic spectral decomposition tool for analyzing the HSI data and producing Naval products.

4.4 Spacecraft Characteristics. The spacecraft system architecture consists of eight hardware subsystems plus a software subsystem, which collectively accommodate the spacecraft payload and meet the mission and science requirements. These subsystems are: (i) the Attitude Determination and Control Subsystem (ADCS); (ii) the Electrical Power Subsystem (EPS); (iii) the Reaction Control Subsystem (RCS); (iv) the Thermal Control Subsystem (TCS); (v) the Structural Subsystem; (vi) the Mechanisms Subsystem; (vii) the Command, Telemetry, and Data Handling Subsystem (CT&DH); (viii) the Communications Subsystem; and (ix) the Flight Software Subsystem.

Figure 4 shows a concept of the NEMO spacecraft in orbit. Table 3 provides an overview of the subsystem characteristics of the NEMO spacecraft.
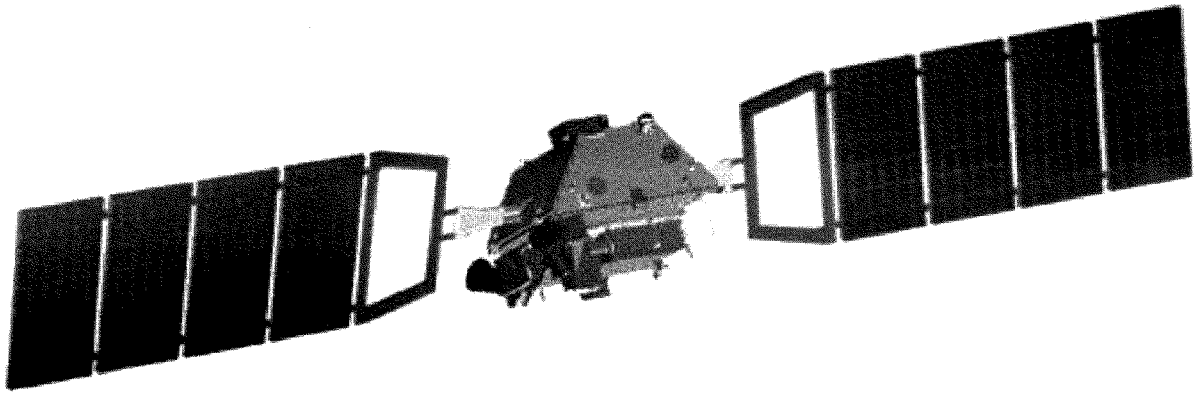
Figure 4. Spacecraft Concept

Table 3. NEMO Spacecraft Characteristics

Subsystem	Characteristics
Attitude Determination and Control	▪ 3-Axis stabilized for all modes; 0.07 degree control ▪ Geolocation: 30 m with a Circular Error of Probability (CEP) of 0.9 ▪ 2 star trackers and 1 inertial measurement unit for attitude determination ▪ 4 reaction wheels and 2 electromagnetic torquers for attitude control
Electrical Power	▪ 2 gimbaled (single axis) solar array panels ▪ 4 for 3 redundant power control box ▪ 64 Ah nickel hydrogen battery ▪ Approximately 1500 watts
Reaction Control	▪ Monopropellant hydrazine blowdown system ▪ 1 propellant tank (76.5 kg capability) ▪ 5 x 1N thrusters for orbit correction/orbit maintenance
Thermal Control	▪ Passive thermal control with heater augmentation ▪ Battery and payload panels thermally isolated from bus
Structures	▪ Primary structure is a combination of a rigid aluminum tubular frame and aluminum honeycomb shear panels ▪ Kinematically decoupled optical bench ▪ Space vehicle mass: ≈496 kgs dry; ≈574 kgs wet; payload ≈292 kgs
Mechanisms	▪ Optical bench launch restraints ▪ Contamination covers for sensors ▪ Solar array drive mechanisms for gimballing arrays ▪ Launch vehicle separation ▪ Two redundant main electrical umbilical connectors
Command, Telemetry, and Data Handling	▪ NEMO Spacecraft Controller (NSC): Mongoose V (radiation-hardened processor) ▪ NEMO Payload Controller (NPC): R3000 processor ▪ Imagery On-Board Processor (IOBP): multiple SHARC processors in a parallel array ▪ 56 Gb solid state data recorder
Communications	▪ Command and Telemetry Uplink: S-Band 2kbps, 2074.18 MHz ▪ Primary Imagery Data Downlink: X-Band 131 Mbps 8.2 GHz, with telemetry embedded ▪ Tactical Demonstration Imagery Downlink: S-band,1.024 Mbps 2252.5MHz (DMSP frequency)
Software	▪ On-board task scheduling capability ▪ Embedded fault detection, isolation, and recovery (FDIR) ▪ Attitude control interface and functionality ▪ Spacecraft Command Language (SCL) for enhanced "macro" commanding

4.5 Mission Operations. The NEMO program will use a combination of commercial operations and existing Defense infrastructure to provide the Naval, DoD, and commercial communities easy and timely access to data collected by the NEMO spacecraft. The NEMO program concept for data handling on the ground is shown in Figure 5. The Navy operations concept is shown in Figure 6.
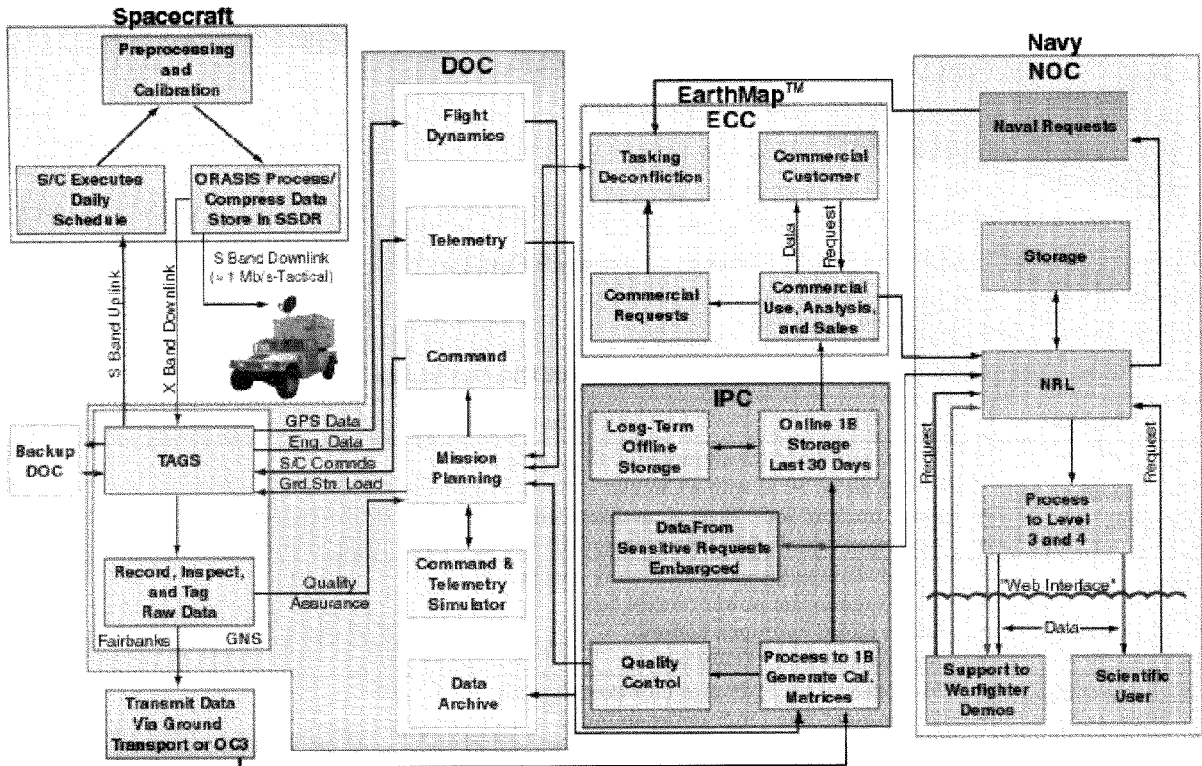

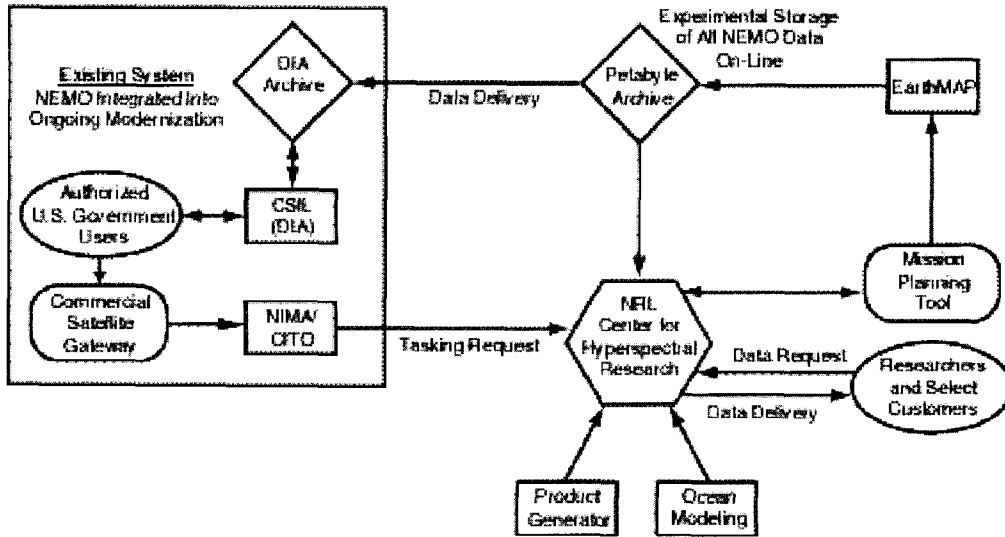Figure 5. NEMO Mission Operations Block Diagram

Figure 6. Ground Data Handling Concept Block Diagram

NEMO operations with be handled through the Advanced Spacecraft Operations Center (ASOC) which will be the central hub for NEMO mission planning, S/C operations, downlink data processing, command generation, and S/C and payload state-of-health monitoring.

The ASOC communicates with the S/C through Transportable Autonomous Ground Stations (TAGS) located in Fairbanks, Alaska, and at another site yet to be determined. The primary feature of the ASOC is that it consists of similar but enhanced elements of existing facilities. This approach effectively combines the cost savings benefits provided by reuse with the productivity enhancements of advanced technology. The ASOC also includes late-model, high-end work stations and PCs. These platforms have the capability to drive the operation of several automated ground stations and provide simultaneous displays for multiple satellites.

The TAGS tracks the NEMO S/C, sends commands to the satellite from the ASOC via S-Band uplink, and receives satellite health and welfare data embedded in the primary payload image data via X-Band downlink. Downlinked data is maintained on mass storage devices at the TAGS until final receipt at the Image Processing Center (IPC) is verified.

The Image Processing Center (IPC) interfaces with the ASOC to receive telemetry and imagery data. The IPC performs the image quick-look (quality control), data processing to Level 1B, and data archive functions. Activities also include fault tolerant data storage, analysis, and retrieval and in-flight sensor calibration.

The NRL Center for Hyperspectral Research (NCHR) is the Naval and scientific hub for the NEMO program. The NCHR performs the tasking for the Navy of the NEMO spacecraft and data distribution function for the Naval segment of the mission, and is the focal point for Naval Hyperspectral research.

4.6 Navy Tactical Demonstration. Currently NEMO is being designed with the ability to downlink directly to the "field" to demonstrate the use of hyperspectral data to the warfighter. An S-Band 1 Mbps transmitter along with the IOBP and ORASIS™ will allow real-time processing and downlinking of data products. The current demonstration scenario is as follows:

The NEMO spacecraft is pre-programmed with an image target command from the Fairbanks ground site.

The NEMO S/C enters the "demonstration area" and images the pre-programmed 30 x 5 km area. Imaging takes about 4 seconds.

In real-time the IOBP processes the image using the ORASIS™ processing algorithm. It crops the image down to a 5 x 5 km area of interest, then processes it into an ORASIS™ product. ORASIS™ reduces a 470 Mbit raw image into a much more managable 60 Mbit product.

The result is downlinked to a deployed field station via a 1 Mbps S-band antenna. This takes about 60 seconds.

A custom interface to the deployed field station will be provided by the NEMO team. This interface will have all the tools required to exploit the hyperspectral imagery.

4.7 On-Orbit Calibration and Product Validation. The NEMO program requires the routine imaging of 50 sites to maintain the calibration of the COIS instrument and for the development, validation and demonstration of coastal ocean products. Characterization and careful laboratory calibration to National Institute of Standards and Technology (NIST) standards of the COIS and PIC instruments will be conducted before flight and during thermal-vacuum testing. NRL will team with the instrument builder to establish the necessary tests and measurement procedures which will be incorporated as part of the instrument acceptance testing. The results will be used to create the initial calibration matrices, and software necessary to correct for any identified instrument abnormalities. On orbit COIS is designed to be stable to better than 1% per month. COIS calibration will be maintained on orbit by monthly imaging of the near full moon, daily stability checks using an on-board calibration lamp, and weekly imaging of large uniform ground reference targets, such as the Sargasso Sea and the Bonneville Salt flats, which have known and monitored reflectances. Moon imaging makes it possible to image reflected sunlight off of a known reflectance target without having to correct for the atmosphere. The moon imaging is currently being used by the SeaWiFS program,[16] the MODerate resolution Imaging Spectrometer (MODIS) program. Imaging known reflectance targets on the earth provides a means for checking the combined accuracy of calibration and atmospheric correction. NEMO will use a new atmospheric correction algorithm based on the Ahmed and Fraser[17] radiative transfer code which includes a correction for sun glint reflected off of the sea surface for water scenes[18].

An additional ten coastal ocean sites will be used for the development, and validation of the standard ocean products and models. Standard products include phytoplankton chlorophyll, colored dissolved organic matter, suspended sediments, Kd(490) (diffuse transmission of light at 490 nm), bathymetry and bottom types. Measurements of these parameters from ships and moorings will provide ground truth for validation of the algorithms. Advanced products, such as spectral absorption and beam transmission, will also be developed at these sites as part of the NRL Hyperspectral Characterization of the Coastal Ocean (HCCO) program and the ONR Hyperspectral Coastal Ocean Dynamics Experiment (HyCODE). Those programs include the use of the NEMO products in the development and validation of coupled bio-optical physical models of the dynamics of the coastal ocean. The ultimate goal is the development of models for the prediction of the coastal ocean environment that are similar to today's weather forecasts for the atmosphere. An iterative process for the development of these models is outlined in Figure 7. The products and models will then be applied to additional sites of interest for science and naval applications.
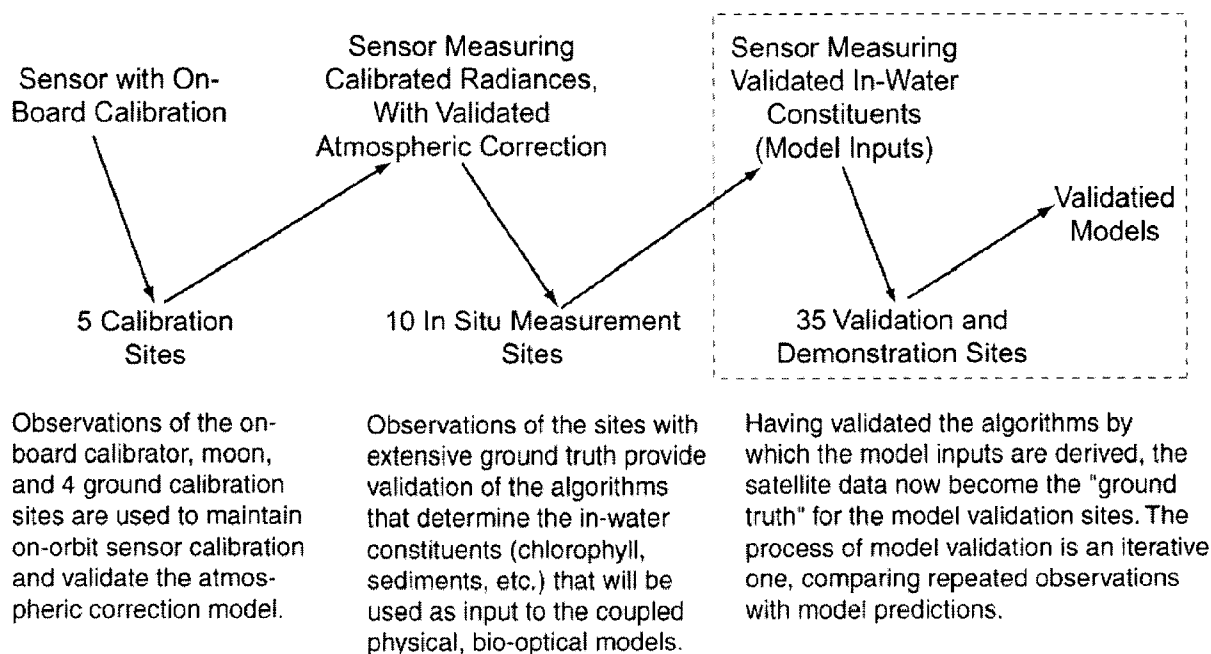
Sensor with On-Board Calibration

Sensor Measuring Calibrated Radiances, With Validated Atmospheric Correction

Sensor Measuring Validated In-Water Constituents (Model Inputs)

Validatied Models

5 Calibration Sites

10 In Situ Measurement Sites

35 Validation and Demonstration Sites

Observations of the on-board calibrator, moon, and 4 ground calibration sites are used to maintain on-orbit sensor calibration and validate the atmospheric correction model.

Observations of the sites with extensive ground truth provide validation of the algorithms that determine the in-water constituents (chlorophyll, sediments, etc.) that will be used as input to the coupled physical, bio-optical models.

Having validated the algorithms by which the model inputs are derived, the satellite data now become the "ground truth" for the model validation sites. The process of model validation is an iterative one, comparing repeated observations with model predictions.

Figure 7. NEMO COIS Sensor Calibration, Product Validation and Model Development

5. Summary

The NEMO program will provide the Navy and DoD with the ability to test and demonstrate the utility of environmental hyperspectral remote sensing to support the warfighter. In addition, the NEMO program along with the NEMO spacecraft provides the opportunity to apply several important technologies to dual-use remote sensing missions. These include innovations in sensors and algorithms; experience in low-cost, high-volume satellite data production; experience in small-staff, automated ground operations; and innovations in image processing and data distribution. The launch date for NEMO has not been set yet. The commercial partner continues to seek necessary commercial capital to complete the program.

6. Acknowledgments

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