2011 HyspIRI Science Symposium

Meeting Focus:

Identifying Potential Higher Level Products for HyspIRI End Users and a Data Management Framework for Global HyspIRI Products

Meeting Objectives:

Identify science/application data products to be derived from HyspIRI measurements by users,

Discover/Discuss issues underlying data product processing/integration/fusion,

Prioritize the development of product prototypes

A Symposium Sponsored by NASA

Goddard Space Flight Center

May 17-18, 2011

Organizer: Dr. Elizabeth M. Middleton, 614.4

Day 1: May 17, 2011

8:00-9:00am	***Registration/Coffee/Posters Hung***	
9:00- 9:20am	Meeting Welcome	*(Nick White, Director 600)*
	Status of HyspIRI Mission	*(Woody Turner, HQ)*
	Meeting Overview, Goals & Logistics	*(Betsy Middleton, GSFC)*

Session I: Background & Framework-- Building on Past Experience

9:20-9:30am	Update on HQ Perspective (*Jack Kaye, HQ*)
9:30-9:50am	Short Summary of the HyspIRI VSWIR Spectrometer (*Rob Green, JPL*)
	Short Summary of the HyspIRI TIR Instrument *(Simon Hook, JPL)*
9:50- 10:00am	Challenges and Opportunities for the HyspIRI Community *(Betsy Middleton, GSFC)*
10:00-10:20am	MODIS Science Algorithms and Data System-- Lessons Learned *(Robert Wolfe, GSFC)*
10:20-10:40am	Lessons Learned from Three Decades of Landsat Collections *(Jeff Masek, GSFC)*
10:40-10:45am	***Discussion***
10:45-11:00am	***Coffee Break/Posters***

Session II: New Possibilities for Science with HyspIRI—General Ideas

11:00-11:20am	Global/Seasonal Imaging Spectroscopy Measurements of the Terrestrial Earth System for Climate Feedback Process Understanding *(Rob Green, JPL)*
11:20-11:40am	Scaling Biosphere-Atmosphere Fluxes from the Site-Level to the Globe Using Machine Learning Algorithms: Lessons for HyspIRI *(Hank Margolis, U Laval)*
	11:40-12:00pm Societal Impacts: Agricultural Perspective *(Charlie Walthall, USDA)*
12:00-12:20pm	CEOS-WGCV Land Product Validation Sub-Group Activities: Current and Potential Roles in Future Decadal Survey Missions *(Miguel Román, GSFC)*
12:20-12:30pm	***Discussion***
12:30-1:30pm	***Lunch [sandwiches/salad/sodas@$9pp]***

Session III: New Possibilities for Science with HyspIRI—Examples

1:30-1:50pm	Coral Reefs, Climate Change, and Remote Sensing *(Eric Hochberg, Nova SE U. Oceanog. Center)*
1:50-2:10pm	The Conundrum of Impacts of Climate Change on Urbanization: Prospects for Using HyspIRI Data Products for Regional to Global Societal Impacts Analysis *(Dale Quattrochi, MSFC)*
2:10-2:30pm	Mapping Coupled Carbon Assimilation and Transpiration Fluxes using TIR and Hyperspectral Imaging *(Martha Anderson, USDA)*
2:30-2:50pm	Advancing the Use of Remote Sensing Information for Quantifying Photosynthetic Efficiency in Space and Time (*Rasmus Houborg, EU Joint Res. Centre, Italy)*
2:50-3:10pm	Thermal Remote Sensing and the Thermodynamics of Ecosystem Development (*Jeffrey Luvall, MSFC)*
3:10-3:30pm	Global Volcano Monitoring and Volcanic Hazard Assessment: How HyspIRI Improves Upon and Complements Results Obtained during the EOS Era (*Robert Wright, U. Hawai'i*)
3:30-3:50pm	***Coffee Break/Posters***

Session IV: Data Volume Challenges & Solutions

3:50-4:10pm	Managing NASA Satellite Data for Global Studies *(Ed Masuoka, GSFC)*
4:10-4:30pm	Status of the Prototyping Efforts for the IPM & Low Latency Products *(Dan Mandl, GSFC)*
4:30-4:40pm	***Topic Introduction for Panel Discussion*** *(Bob Knox, GSFC)*
4:40-5:50pm	***How do we handle HyspIRI data? What is the preferred Mission Model for the data processing chain?***
	Panel Members: Bob Knox (Chair), Robert Wolfe, Ed Masuoka, Dan Mandl, Rob Green, Simon Hook
5:50-6:00pm	***Wrap-Up and Announcements***
6:00pm	***Adjourn for the Day***
7:00-8:30pm	**DINNER (at Ruby Tuesday – in alcove by bar; restaurant across from GSFC Main Gate)**

Day 2: May 18, 2011

8:00-9:00am ***Registration/Coffee/Posters Hung***

8:15-9:00am ***Coffee/Posters***

Session V: Context for Hyperspectral and TIR Data Products

9:00-9:20am	Hyperspectral Remote Sensing of Vegetation: Knowledge Gain and Knowledge Gap after 40 years of research *(Prasad Thenkabail, USGS)*
9:20-9:40am	How will remote sensing of volcanic activity evolve with HyspIRI? (*Mike Ramsey, U. Pittsburgh*)
9:40-10:00am	Summary, 2010 HyspIRI Symposium on Higher Level Products *(Betsy Middleton, GSFC)*
10:00-10:20am	Report on Two HyspIRI Workshops to Identify Climate Relevant Products at the Global Scale *(Susan Ustin, UC-Davis)*

Session VI: Data Issues

10:20-10:40am	Sampling and Time Series Issues *(Bob Knox, GSFC)*
10:40-11:00am	***Coffee Break/Posters***
11:00-11:15am	Tagging and Retrieving Data for an Archive *(Dave Landis, Sigma Space)*
11:15-11:30am	Data Processing Tools *(Vuong Ly, GSFC)*
11:30-11:45am	Calibration & CEOS *(Steve Ungar, USRA)*
11:45-12:00pm	AERONET *(Sasha Smirnov, Sigma Space)*
12:00-12:15pm	Calibration and Validation Sensors for Next-Generation NASA Missions *(Stan Hooker, GSFC)*
12:15-12:35pm	Use of HyspIRI Data with the Web Coverage Process Service (WCPS) for Environmental Monitoring – Pre-Launch Demonstrations Using SensorWeb Hyperion Data *(Robert Sohlberg, UMD)*
12:35-12:45pm	***Discussion***
12:45-1:30pm	***Lunch [sandwiches/salad/sodas@$9pp]***

Session VII: Prototyping with EO-1, AVIRIS, Spectrometer, and MASTER/ASTER Data

1:30-1:50pm	A Global Volcano Product for Thermal Emission and Effusion Rate *(Steve Chien/Ashley Davies, JPL)*
1:50-2:10pm	NEON: Extending Site-based Observations to the Continental Scale Using Airborne and Satellite Remote Sensing *(Brian Johnson, NEON)*
2:10-2:30pm	Estimation of Rangeland Changes & Evapotranspiration Using Multispectral Thermal Infrared Data (*Andy French, USDA*)
2:30-2:45pm	Integration Photochemical Reflectance Index (PRI) and fAPARchl Products for Carbon Monitoring *(Yen-Ben Cheng, ERT)* 2:45-3:00pm Remote sensing estimates of ecosystem GEE using fAPARchl and PRI *(Qingyuan Zhang, USRA)*
3:00-3:15pm	Spectral time series to monitor vegetation dynamics using EO-1 Hyperion *(Petya Campbell, UMBC)*
3:15-3:30pm	Determining Ecosystem Carbon Flux from Spectral Reflectance for Multiple Sites: Implications for Global Sampling *(Fred Huemmrich, UMBC)*
3:30-3:45pm	G-LiHT: Goddard's Lidar-Hyperspectral-Thermal airborne imager (*Bruce Cook, GSFC*)
3:45-3:50pm	***Topic Introduction for Break-Out Session Discussions*** *(Betsy Middleton, GSFC)*
3:50-4:05pm	***Coffee Break***

Session VIII: Higher Level Regional/Global Products

4:05-5:00pm	***Two Break-Out Session Discussions: What are the Priority Higher Level Regional/Global Products?*** ***Group** 1* (*Prasad Thenkabail*) ***Group Two*** (*Petya Campbell*)
5:00-5:20pm	***Report from Break-out Session Discussions*** (*Prasad Thenkabail and Petya Campbell*)
5:20-5:40pm	***General Discussion***
5:40-5:50pm	**Symposium Summary (*Woody Turner*)**
5:50pm	***Adjourn Symposium***

In addition to the Agenda, the following reports are included in this document:

1] Symposium Overview**,** written for the ***Earth Observer*,** to appear in August 2011, *4pp*.
Elizabeth M. Middleton, NASA Goddard Space Flight Center, K. Fred Huemmrich, University of Maryland Baltimore County, and Yen-Ben Cheng, Earth Resources Technology, Inc.

2] Lessons Learned from Landsat, MODIS, EO-1, and Their Data Systems: A Summary of the HyspIRI Presentations by J. Masek, R. Wolfe, E. Masuoka, and D. Landis, *David Landis (GSFC/Sigma Space, Inc.), 3pp.*

3] Panel Discussion: Data Volume Challenges & Solutions, with *Panel Members:* Bob Knox (Chair), Rob Green, Ed Masuoka, Dan Mandl, Karen Moe, *Bob Knox (GSFC)*, 2 pp.

4] Breakout Session Discussions: *"Priority HyspIRI Higher Level Regional/Global Products*", *Petya Campbell (GSFC/UMBC), 5 pp.*

APPENDIX 1: Higher Level Products for HyspIRI – *Discussions Summary*

2011 HyspIRI Science Symposium (*Earth Observer*, August 2011)

Elizabeth M. Middleton, NASA Goddard Space Flight Center, Elizabeth.M.Middelton@nasa.gov
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Yen-Ben Cheng, Earth Resources Technology, Inc., Yen-Ben.Cheng@nasa.gov

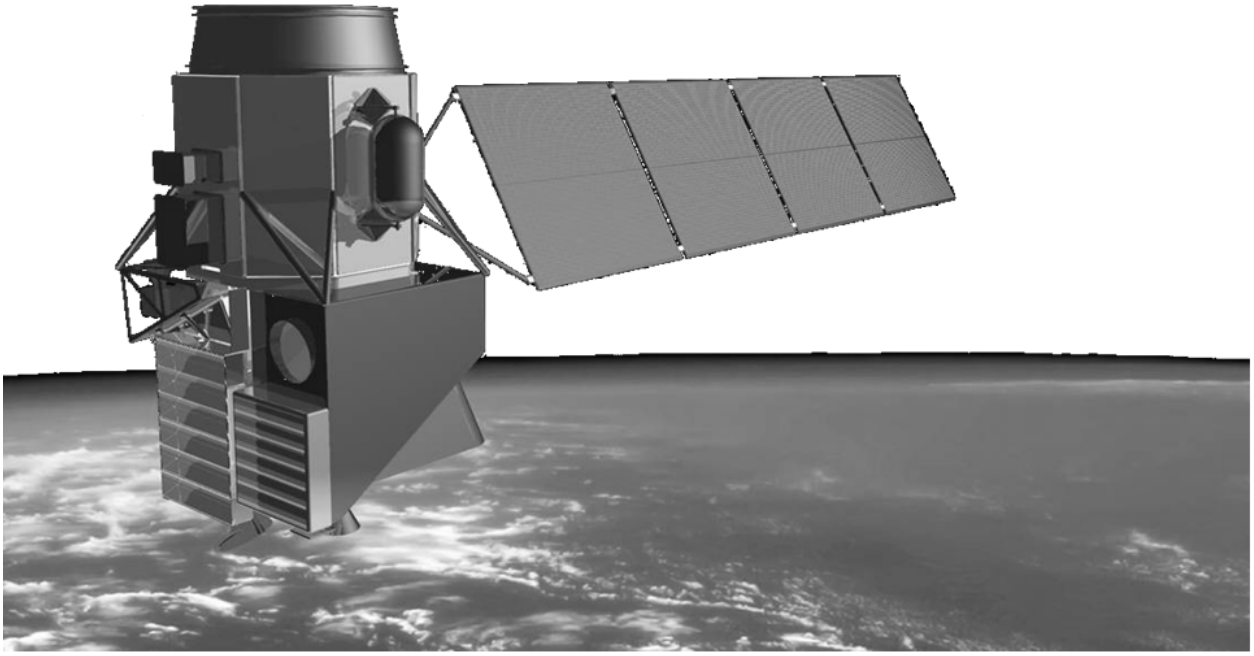

Illustration of the NASA Decadal Survey Mission HyspIRI in orbit

The Hyperspectral Infrared Imager (HyspIRI) mission is one of the missions recommended in the National Research Council (NRC) Earth Science Decadal Survey. HyspIRI will fly an imaging spectrometer measuring the visible to short wave infrared (VSWIR) spectrum and a multispectral thermal infrared (TIR) imager. HyspIRI data will be used to study terrestrial and coastal ecosystems and carbon cycle parameters, along with supporting geological studies, such as volcano observations. The 2011 HyspIRI Science Symposium on Ecosystem & Environmental Data Products was held at the NASA Goddard Space Flight Center (GSFC), Greenbelt, MD on May 17 - 18, 2011. Approximately 84 participants from academic institutes and government agencies joined us in the two-day event. Following the successful symposium held in 2010, this year's meeting focused on identifying potential higher level products for ecosystems and environment at regional and global scales, along with the requirements for a data management framework to process and deliver HyspIRI data. A total of 40 talks and 7 posters were presented. The presentations covered the background and activities of the HyspIRI mission, product integrity and availability, and science and applications from the user community. Potential higher level HyspIRI terrestrial ecology products were identified and proposed, and consensus discussions were initiated.

Background and Framework--Building on Past experience

Nick White [NASA GSFC] welcomed everyone to GSFC and commented on the Center's perspective to support the HyspIRI mission.

Woody Turner [NASA Headquarter (HQ)--Co-Program Scientist for HyspIRI] provided an update on the status of the HyspIRI mission. He noted the HyspIRI Summative Briefing to NASA HQ in 2010, and outlined the need for future work to enhance the maturity of the mission concept and advance the scientific case for the mission.

Betsy Middleton [NASA GSFC] presented the overall objectives and logistics of the meeting; identifying science and application data products from HyspIRI, discussing issues underlying data product processing and integration, and prioritizing the development of products and algorithms. She also pointed out an expected report summarizing the outcome of this symposium would be written.

Jack Kaye [NASA HQ--Associate Director for Research and Analysis, Earth Science Division] provided an update from HQ perspective on the status of the Decadal Survey missions and how the HyspIRI mission fits into the overall program.

Rob Green [NASA Jet Propulsion Laboratory (JPL)] summarized the HyspIRI VSWIR imaging spectrometer, which will provide observations over the 380-2500 nm spectral region with a 10 nm spectral resolution and a 19-day revisit time. With the global coverage and 60 m spatial resolution over the terrestrial surface, the HyspIRI VSWIR data will provide valuable observations for climate studies and ecosystem monitoring.

Simon Hook [NASA JPL] summarized the HyspIRI TIR instrument. The multispectral TIR imager on HyspIRI will acquire data in eight spectral bands between the spectral region of 4 -12 μm with a nominal 5-day revisit time. A wide range of science and application examples were given to show how the TIR data would be utilized, including studies of volcanoes, wildfires, and water use/availability.

Betsy Middleton [NASA GSFC] presented the opportunities and challenges of the HyspIRI mission, pointing out how the HyspIRI mission could contribute to NASA's strategic goal to advance Earth System Science and meet the challenges of understanding climate and environmental change. HyspIRI can provide key information for objectives of the NRC Decadal Survey and International Panel on Climate Change (IPCC) including ecosystem feedbacks for climate change, water resources management and sustainability, and critical volcano eruption parameters. Nevertheless, issues including data processing, calibration, and validation need further discussion and efforts.

Robert Wolfe [NASA GSFC] shared the successful experience and lessons learned from the Moderate Resolution Imaging Spectroradiometer (MODIS) mission. Wolfe pointed out the importance of leadership and communications within the community. Various issues including data systems, algorithm development, quality assurance, calibration and applications were reviewed. He examined issues that arose from each of the MODIS disciplines, oceans, atmosphere, and land, and how they were resolved.

Jeff Masek [NASA GSFC] reviewed the 40 years of the Landsat mission. He summarized the contributions that the continuous Landsat observations made to important science and application studies including land surveys, forest dynamics, disturbance and recovery. He emphasized the value of having frequent coverage and lessons from the development of Landsat global products that the HyspIRI mission can apply.

New Possibilities for Science with HyspIRI--General Ideas

Rob Green [NASA JPL] presented how the HyspIRI mission will provide unprecedented opportunity to monitor ecosystems and their responses and feedbacks to the changing climate since HyspIRI can provide information about vegetation species, functional types, biodiversity, plant chemical and physiological conditions from its measurements. **Hank Margolis** [University of Laval] demonstrated the potential of using a machine learning algorithm to scale carbon exchange between ecosystems and the atmosphere from site level up to global level using remote sensing and meteorological data and the implications of this approach for potential HyspIRI global products. **Charlie Walthall** [USDA] discussed some challenges for agriculture including food safety, adaptation for climate change, and sustainability. Various measurements from local to global scale are needed and the HyspIRI mission can provide an opportunity to improve our current agricultural management. **Miguel Roman** [NASA GSFC] presented the Committee on Earth Observation Satellite (CEOS) Working Group on Calibration and Validation (WGCV) Land Product Validation (LPV) subgroup and their possible collaboration with the HyspIRI mission.

New Possibilities for Science with HyspIRI—Examples

Eric Hochberg [Nova Southeastern U] presented a summary of current coral reef studies, the connections with climate change, and how remote sensing and HyspIRI observations can be utilized. Because of its global coverage, HyspIRI will provide a unique opportunity to quantitatively assess the global status of coral reef ecosystems. **Dale Quattrochi** [NASA Marshall Space flight Center (MSFC)] discussed urbanization, its effects on human health, and responses to climate change. HyspIRI imagery, especially the TIR and day/night acquisitions, will provide measurements for products describing air quality, urban heat islands, and land cover/land use change. **Martha Anderson** [USDA] and **Rasmus Houborg** [EU Joint Research Centre, Italy] presented an algorithm that can utilize HyspIRI VSWIR and TIR data simultaneously to model carbon assimilation and transpiration. Results of test studies over multiple sites were described. **Jeffery Luvall** [NASA MSFC] presented the potential for using HyspIRI TIR measurements to evaluate ecosystem health and integrity through the connection between thermodynamics and ecosystem structural development. **Robert Wright** [U of Hawaii] discussed global volcano monitoring and hazard assessment with future HyspIRI data. The fine spatial and temporal resolution of HyspIRI data coupled with improved accuracy of surface temperature retrievals will significantly advance the ability to describe volcanic activity.

Data Volume Challenges & Solutions

Ed Masuoka [NASA GSFC] shared his experiences in managing the data from MODIS for the scientific community. The infrastructure of MODIS product development, processing, distribution, and response to the needs of the science community provide valuable lessons on how to handle the global coverage of HyspIRI data. **Dan Madl** [NASA GSFC] gave a status update on the intelligent payload module and low latency products. Current efforts focus on taking advantage of parallel processing for efficient computation power and rapid production of low latency data products. **Bob Knox** [NASA GSFC] led a panel discussion with **Rob Green** [NASA JPL], **Ed Masuoka** [NASA GSFC], Karen Moe (NASA HQ), and **Dan Madl** [NASA GSFC] focused on the preferred Mission Model for the data processing chain. Various framework and infrastructure approaches were introduced and discussed to achieve consistency, ensure availability, examine integrity, and maintain continuity of various HyspIRI data product types.

Context for Hyperspectral and TIR Data Products

Prasad Thenkabail [USGS] reviewed past research on hyperspectral remote sensing for vegetation, both natural and managed systems, and the status of our current knowledge. Potential HyspIRI VSWIR products on leaf biochemical and canopy biophysical properties were suggested.

Mike Ramsey [U of Pittsburgh] reviewed the past and current state-of-the-art remote sensing for volcanic activity. Capacities of volcanological remote sensing using TIR measurements have advanced rapidly over the last decade. Future observations, from HyspIRI, can be routinely used in monitoring, modeling, and hazard appraisals.

Betsy Middleton [NASA GSFC] reviewed the successful 2010 HyspIRI Science Symposium with a goal to identify and evaluate potential higher level products for end users of climate studies.

Susan Ustin [U of California, Davis] gave a summary of two workshops on HyspIRI global science products and their relevance for climate change research and modeling. The key message from the workshop was that the spatial resolution, temporal revisit, and spectral characteristics of HyspIRI will significantly advance ecosystem science and provide improved land surface parameterization for climate studies. Further, HyspIRI measurements can contribute critical information about ecosystem responses and feedbacks to climate change.

Data Issues

Dave Landis [Sigma Space] introduced the current design of tagging and developing metadata for the NASA Earth Observing-1 (EO-1) imagery and how this may lead to future approaches for searching HyspIRI data. **Vuong Ly** [NASA GSFC] presented current development of several data processing tools for the EO-1 mission and their potential for HyspIRI. **Steve Ungar** [Universities Space Research Association (USRA)] presented various CEOS activities and calibration topics with implications for HyspIRI. **Sasha Smirnov** [Sigma Space] reviewed AERONET activities. The HyspIRI mission can use AERONET measurements for calibration as well as learn from their successful international network in the development of a calibration/validation network. **Stan Hooker** [NASA GSFC] reviewed various sensors for calibration and validation that were developed to support ocean color satellite missions. **Robert Sohlberg** [U of Maryland (UMD)] showed web-based data processing tools for environmental monitoring.

Prototyping with EO-1, AVIRIS, Spectrometer, and MASTER/ASTER Data

Steve Chien [NASA JPL] showed a global volcano product based on the current EO-1 Hyperion Volcano SensorWeb. **Brian Johnson** [National Ecological Observatory Network (NEON)] discussed data product prototyping by NEON and their activities to integrate data acquired at various spatial scales. **Andy French** [USDA] presented on the potential of using HypsIRI TIR data for estimates of rangeland changes and modeling energy fluxes. **Qingyuan Zhang** [USRA] gave an update on a potential HyspIRI science product, the Fraction of Absorbed Photosynthetic Active Radiation at Chlorophyll level (fAPARchl), a radiative transfer modeling based parameter that can help to improve the estimation of carbon fluxes over multiple sites of natural and managed ecosystems. **Yen-Ben Cheng** [Earth Resources Technology, Inc. (ERT)] presented an algorithm that integrated two of potential HyspIRI products; Photochemical Reflectance Index (PRI) and fAPARchl to estimate carbon assimilation with a discussion of possible effects due to spatial resolution. **Petya Campbell** [University of Maryland Baltimore County (UMBC)] utilized time series of EO-1 Hyperion imagery to demonstrate the use of multiple narrow spectral bands to monitor a range of ecosystems and their carbon exchange. **Fred Huemmrich** [UMBC] presented the concept of using PRI from MODIS narrow ocean bands for ecosystem carbon monitoring at multiple sites and implications for global sampling of HyspIRI. **Bruce Cook** [NASA GSFC] introduced a newly developed integration of multiple instruments, including an imaging spectrometer, thermal imager, and lidar, that can be flown on a light aircraft for carbon and ecosystem monitoring.

Break-out Session Discussions: Higher Level Regional/Global Products

Prasad Thenkabail [USGS] and **Petya Campbell** [UMBC] led two break-out discussion sessions. Various potential HyspIRI higher level products at regional and global scale were discussed. Other topics included enhancing communication about thermal sensing and imaging spectroscopy both within the scientific community and the general public, along with ideas on data and algorithm sharing within the HyspIRI community.

Summary

In general, participants recognized the planned HyspIRI mission will provide the science community with extremely valuable information on plant physiological condition and energy exchange between the atmosphere and terrestrial ecosystems. Potential higher level product at regional to global level will addressed science questions from various disciplines including ecosystem monitoring and modeling, biodiversity and climate change. Successful utilization of HyspIRI data will require the development of an information system that builds upon the lessons learned from past missions such as MODIS and Landsat.

Lessons Learned from Landsat, MODIS, EO-1, and Their Data Systems

A Summary of the HyspIRI Presentations by J. Masek, R. Wolfe, E. Masuoka, and D. Landis

Report prepared by David Landis (GSFC/Sigma Space, Inc.)

Product Availability

- Government-funded operation of both satellite and data system have enabled free and open distribution of data. Prices can be too high for scientists to purchase images at the levels required for commercial profitability.
- We have found that use of the data is inversely related to what users are charged for the data. The higher the cost, the fewer users. The lower the cost, the more users. The best price for data is free! Even minor charges (like processing fees) will inhibit the usage and distribution of data.

Data Product Processing and Formats

- Size standard products to facilitate processing, distribution and ease of use:
  - For MODIS products, sizes are 5 minutes of swath data (Level 1 and Level 2) and 10 degree x 10 degree tiles (Level 3)
  - Majority of products should be less than 500MB per file when compressed.
- Specialized products help meet emerging needs. Some products should be in Climate Modeling Grid for climate modelers. Others users need gap filled-products for their models.
- GIS-ready products and imagery and application specific formats are essential.
- The less customized encoding (HDF, NetCDF, etc.) the better. Power users should be able to reprocess the image data directly, not have to decode it first. This does not apply to standard compression routines (ZIP, Gzip, etc).
- A robust pre-processing approach is important. Prescreening the data for clouds, shadows, water, (etc.) makes processing the images much easier.
- Higher-level (Level 3+) products are more useful as standard products that can be compared across various satellite platforms.
- One map projection (grid spacing, etc.) will not work for all users (or even a majority).
- Advice on science testing of algorithms:
  - Don’t bundle too many changes together – impacts of upstream algorithms are hard to untangle.
  - Storage is needed for multiple baselines and changes.
  - Maintain a basic set of science test days.
  - It is useful to have the same algorithms across multiple sensors. For example, adapting the heritage SeaWIFS Ocean Color algorithm for Aqua made it possible to produce a good quality product.
- Science team members should play a key role in development and maintenance of code, and they should remain responsible. The science team should lead the processing to ensure that the best products are generated and reprocessed with a workable schedule.
- Product development should be a well-defined process that allows for community feedback.
- Metadata for the images is critical to make it usable. The more that the images can be categorized by content, the better for future studies. Extra effort put into image categorization yield additional benefits later in the project.
- Keep the products simple and well-documented.

Image Reprocessing

- Reprocess the baseline data products as little as possible. Users want access to the original information, not data that has been averaged, smoothed, and otherwise massaged by unknown algorithms.
- Having Level 0 data on-line makes science testing and reprocessing much easier.
- If reprocessing is deemed necessary, it should be well-documented to allow users to understand what was done to the data, and to decide if the reprocessed data meets their needs. Alternatives to the reprocessed data should also be available.

Calibration and Cross-Platform Calibration

- Sensor calibration and cross-platform recalibration are critical for the record of satellite data.
- Cross-calibration with other sensors is vital to the integration of data products.

Data Systems and Distribution

- On-line products (including Level 0) greatly increase the speed and simplicity of data distribution.
- A robust data system enables processing-on-demand for tailoring products as well as Web services.
- The MODIS Adaptive Processing System (MAPS):
  - Scalable system for MODIS, AVHRR, VIIRS and Landsat processing were designed so that processing resources can be easily moved where needed.
  - Achieved significant savings (50% or more) purchasing servers in volume of 100+ but even greater savings in manpower by adding new missions and applications within the data center.
  - Building with commodity hardware makes it easier to scale, saves money, and is easier to do a technology refresh.
  - Built with open source components: Linux, Apache, Perl, Postgres, Subversion, FUSE.
  - Leveraging tools, procedures and staff experience for land product quality assessment from MODIS and VIIRS allowed us to meet schedule and cost targets.
  - Designed to run with limited staff:
    - "Lights out" processing outside of normal business hours
    - Months of processing can be queued up and execute without human intervention
    - Alerts emailed to system administrators when hardware components generate warnings or fail
    - Easy to use tools for monitoring the system (Ganglia) and investigating failed jobs
  - Rapid updating for provisioning of servers with science processing software, the operating system and applications (Depot and SATE).
  - Impact of Moore's Law (increasing capability at decreasing cost) on computation and storage has made many things possible and allowed requirements to grow with increased capacity and performance.

Outreach (quick response, direct broadcast, disaster mode)

- A Near Real Time (NRT) data system is needed for application users:
  - A stand alone NRT system is needed to avoid gearing the entire production stream to the NRT constraints.
  - Direct Broadcast (DB) versions of code make it easier for broad product uptake and use – increases standardization.
  - DB encourages applications and regional algorithm development and has been a huge success with > 100 direct readout sites worldwide.
- Targeted outreach programs are needed:
  - Imagery support is needed for outreach.
  - Earth Observatory for one-stop shopping – must include good descriptions (captions) – this is a good way to deal with the Media.

Science Teams, Staffing

- Weekly team meeting should be held to keep everyone on same page.
- Full science team meetings should be held twice per year early in mission, once per year later.
- Discipline leaders and a core full-time group should be built around the data system. A close working relationship among data team and science team members is important.
- A core calibration group should have representation from the various science disciplines. Discipline representatives provide important feedback because they understand calibration and its impact on fundamental (upstream) science products (e.g., water leaving radiance, land surface temperature, land surface reflectance, aerosols).

Long-Term Advice

- Always build as much capability into the flight hardware as possible. Always assume that the satellite and instruments will last much longer than the original requirements.
- A small, dedicated data system is needed for algorithm refinement, integration/testing, and demonstration/evaluation of readiness in the years leading up to launch.
- Science team members should be funded before and through the life of the instrument – a long term commitment and experience base is critical.
- Time dedicated by science experts is the most valuable resource for making high quality products but hardest to fund over the long haul.
- Immortality of key personnel is not a viable alternative to succession planning. Always have new people coming into the project and learning about vital systems. Make sure no person is irreplaceable.

Panel Discussion: Data Volume Challenges & Solutions

Panel Members: Bob Knox (Chair), Rob Green, Ed Masuoka, Dan Mandl, Karen Moe

Report Prepared by Bob Knox (GSFC)

This discussion was framed by two over-arching questions: "How do we handle HyspIRI data?" and "What is the preferred Mission Model for the data processing chain?" Bob Knox offered a (blank) matrix of science data system functions (rows) and groups of HyspIRI data product types (columns). To help stimulate discussion he then offered a list of example architectures that might be used to support one or more functions for one or more groups of data products. The examples ranged from relatively established NASA models, such as, distributed active archive centers (DAAC), science investigator processing systems (SIPS), and direct broadcast of selected products; to less familiar potential architectures for serving mission science data, such as cloud-based virtual data centers (run by NASA and/or international partners), or peer-to-peer distribution of data subsets temporarily in high demand (*e.g.,* via a GeoTorrent protocol). Schedule conflicts with MODIS calibration meetings prevented two of the announced panel members from attending. Karen Moe of NASA's Earth Science Technology Office (ESTO) generously agreed to participate. Knox concluded by briefly introducing the panel members.

Then the other panel members each spoke for a few minutes. Karen Moe noted several ESTO-supported technologies of relevance to the subject, including three included in the baseline concept for HyspIRI's Intelligent Payload Module (addressed by Dan Mandl in a preceding talk). NASA has been supporting development of service oriented architectures, especially using the Open Geospatial Consortium specifications for web services (web map services, web coverage services, *etc.*). Semantic web technologies may make HyspIRI data more easily searched and found by potential users. This should reinforce importance of managing metadata and data provenance. Work on collaborative environments can help the community developing potential HyspIRI algorithms and products work together and capture findings of previous work. Also in the area of data intercomparison (*e.g.,* for product validation or change detection and measurement), there has been research on new methods of modeling and managing data uncertainty. Having spoken earlier on lessons learned from managing MODIS data for global studies, Ed Masuoka noted that HyspIRI will be generating long-term records—in the context of other operational and systematic missions, as well as potential follow-on missions providing global multispectral thermal and imaging spectrometer data. He also advised that HyspIRI may benefit from technologies that are coming down the pike, without our having to pay for them. Dan Mandl emphasized the value of flexible low-latency products (e.g., reconfigurable direct broadcast) for certain user communities, and noted the potential for further use of the EO-1 mission as a test-bed for technologies relevant to HyspIRI.

On the topic of information technology clouds, discussions noted the flexibility clouds may offer for surges in processing, such as rapid re-processing of HyspIRI data with new or updated algorithms. On the other hand, communication bottlenecks in present and near-term information processing technology make it efficient to keep the processing as close to the data storage as feasible, whereas staging large parts of the HyspIRI archive into and out of clouds might impose unacceptable overhead. While noting that the HyspIRI mission data system concept is feasible now (much earlier than launch dates implied by the most recent NASA budget), Rob Green recalled the on-going rapid drops in prices for data storage media, noting that a generalized form of Moore's Law continues to be true of much of the relevant technology of information processing and communication systems. For example, the data storage of imaging spectrometer data for the AVIRS lab approaches a Petabyte. Also recently Terrabit-per-second data links have been demonstrated over optical fiber.

A number of other issues and insights emerged during the open discussion period. There remains the question of when to distribute updated large-volume data products, analogous to MODIS numbered data collections, and when to provide updated algorithms to registered institutions or individuals mirroring or holding portions of the level 1 or level 2 HyspIRI archive. An important layer of a HyspIRI architecture, omitted from Knox's list of examples, were other agency data centers, for example, some critical HyspIRI products could be served by a volcano center. In the area of spectral libraries that are essential for algorithm development and to produce some higher-level data products, HyspIRI needs a mechanism for bringing together the piece-meal spectral libraries that exist now. Because we anticipate that more wide and diverse use of HyspIRI data sets could be enabled by regional and/or disciplinary centers, it may be appropriate to update our data system metaphors. While a NASA-funded archive may hold the most authoritative and complete set of HyspIRI data, analogous to holdings of the Library of Congress, individual data subsets (or books) might be more efficiently provided to users by a network of public and private libraries. The diversity of higher level products implied by the scientific and applications objectives recommended for HyspIRI suggests that many important products will be developed by global communities of scientists and land managers. HyspIRI and NASA will face decisions about what higher-level products to archive (as processed data or as validated algorithms) for long-term use. NASA and the evolving HyspIRI community will also need good mechanisms for tracking the provenance of community-developed data products. As anticipated by the organizers, this panel discussion generated more questions than answers. It can be hoped that it stimulates an on-going exploration of hybrid architectures that could be both cost effective for the NASA and the HyspIRI mission, and also engage diverse global communities of scientists, mission partners, and developers of applications of HyspIRI data.

Breakout Session Discussions: *"Priority HyspIRI Higher Level Regional/Global Products"*
Report prepared by Petya Campbell (GSFC/UMBC)

The two breakout discussion groups were led by Drs. Prasad Thenkabail and Petya Campbell. Each group consisted of approximately 20 participants. The summary below incorporates inputs from both discussion groups. Terrestrial and aquatic products require different inputs, so therefore, they were addressed separately. At the end of the discussion, the participants agreed that such discussions are very much needed and should continue. It was requested that the draft below be circulated among the listed participants for further input: Eric Hochberg, Jeff Morisette, Susan Ustin, Angela Mason, Michael Mercury, Fred Huemmrich, Bob Knox, Karen Moe, Dean Riley, Charles Norton, Steve Chien and Prasad Thenkabail.

The following EOS definitions for Level 3 and Level 4 Products were adapted for further use:

- **Level 3 Products:** Spectral or wavelength-dependent data (radiances, surface reflectance, temperature and emissions, etc.) mapped onto uniform space-time grids, usually with some completeness and consistency; terrain corrected products.
- **Level 4 Products:** Results from analyses of lower level (L1, L2) data, model outputs, data combinations, such as: (i) spectral indices applied to L2 or L3 data; (ii) variables derived from multiple measurements (e.g., time series) of same sensor; (iii) multi-sensor data fusion; and (iv) assimilation with other data types.

1. Proposed HyspIRI Terrestrial products:
Included higher level products (L3 and L4), or L2 if they are not planned

Product Level	Description	Maturity / Use
L2 VSWIR	Surface Reflectance Water vapor content Cloud masks TOA reflectance Surface radiance Incident PAR Albedo (nominal 19 days global albedo)	Mature products, available algorithms For model runs and simulations
L2 TIR	Surface Emissivity (local/regional) Surface radiance Sky irradiance	Mature products, Available from satellite
L3 VSWIR & TIR	Seasonally combined VSWIR&TIR Continuous fields vs. discriminate LC classes All MODIS and Landsat products Bio-indicators of vegetative function	The two data-sets need to be co-located Existing approaches need to be tested at larger scale Need to consider which to continue with HyspIRI Many algorithms available, some currently tested
L4 VSWIR & TIR	Mineral identification and mapping **Urban and human landscapes:** • **2/3 weeks thermal** dynamics • Functional classifiers for urban landscapes New indicators of ecosystem function, diversity and disturbance	Mature, needs global spectral libraries for cal/val Include the urban elements of land cover. Some are currently tested but need further development. Currently developed with simulated HyspIRI data

Product Level	Description	Maturity / Use
L4 SWIR	Global Canopy Water Content Global Canopy Nitrogen Content Global Canopy Cellulose	Mature product Not global Mature algorithm, needs global testing and validation
L4 VSWIR	Global Canopy Chlorophyll Content	Needs further testing, many algorithms available, need to be reconciled for specific use
L4 VSWIR	Global fractional end members	Mature product
L4 TIR	Global ET	Need global testing and cal/val

2. Proposed HyspIRI Aquatic Products *(with a coral reef bias), prepared by Eric Hochberg, NOVA*

Product Level	Description	Maturity / Use
L2 VSWIR	Remote Sensing Reflectance (R_{rs}, units sr^{-1}, 400–800 nm) = water-leaving radiance (L_w) ÷ downwelling irradiance (E_d)	This is the result of atmosphere and glint corrections. There are well-developed and practically operational algorithms for atmospheric correction. Glint correction for shallow water imagery is nearing routine operational status.
L2 TIR	Sea Surface Temperature	Routine product from many satellites
L3 VSWIR	- Seafloor Spectral Reflectance (units %, 400–? nm) - Water Depth - Water Optical Properties - Retrieval Quality Flags	These are combined results from aquatic retrieval algorithms utilizing R_{rs}. There are several candidate algorithms in existence.
	- Fractional Cover	These are derived from Seafloor Spectral Reflectance. There are no existing algorithms, but there have been some basic investigations.
	- Light-Use Efficiencies for (1) Productivity and (2) Calcification - Dissolved Organic Mater (DOM) - Pigments (=chlorophyll)	There are no existing algorithms, and there have been (virtually) no investigations. There are developed algorithms
L3 TIR	Degree Heating Weeks	Routine product
L4 Combined VSWIR&TIR	- Productivity, Gross/Net - Calcification	There are no existing algorithms, and there have been (virtually) no investigations.

The following issues were considered critical for the success of the mission, to prepare the future users and broaden/expand the community (to be addressed ASAP):

- The need of broadly available non-proprietary (if possible) tools for spectral data processing and analysis.
- Establishing/promoting of consistent spectral (and temporal) libraries and depositories (ASAP).
- User pamphlet on spectral collection, and spectral library standards (101 round robin).
- Test Database of thermal and spectral data over the same geographical area, and preferably during the same timeframe: AVIRIS, Hyperion, MASTER, ASTER.
- Develop prototype *global* HyspIRI products, using MODIS and Hyperion imagery scaled to appropriate climate model scale(s) (for use in modeling activities, such as climate change, disturbance, fires, and MODIS/GOES data).
- HyspIRI Bio-Indicator prototypes:
- Compare broad band indices (Landsat and MODIS) vs. higher spectral resolution (various NDVI's, or versions of TM indices).
- Develop and test unique spectrometer spectral parameters/indicators that will be possible with HyspIRI (SWIR 1200:2500, VISWIR&TIR).

The group suggested that it is critical to bring HyspIRI "out" to the user communities, by starting user workshops at society meetings such as: ESA, USFS workshops, FLUXNET, etc. A question was raised if NASA funding may be available for this critical "outreach" activity.

APPENDIX 1: **Higher Level Products for HyspIRI – Discussion Summary**

#	Product	Level (L2/3/4)	Maturity	MODIS	Landsat	Models	Notes
Reflectance & TIR Products							
A.	***Global Products for Data Continuity***						
1	Convolved Reflectance to other sensors (long term data recors; narrowband/broadband)	3	yes	yes	progress	yes	R(%), LEDAPS, WELD algorithms
2	Symulated LST for other sensors (e.g. MODIS, LDCM/TIRS)	2	yes	yes	yes	yes	LST (T C^{o})
3	Fractional land cover type (FLC) [continuous fields, % of land cover: soil, water, vegetation, ice&snow]	3	yes	yes	yes	yes	for long term records continue MODIS product, test f(PV, NPV) for vegetation cover
4	Thermal Anomalies	4	yes		yes/limited	yes	
B.	***Terrestrial (veg. & soil)***						
I.	**Spectral End-member Abundance**	3	in progress	no	no	no	Local Spectral libraries (cal/val) needed
	- mineral maps, veg type maps						
II.	**Vegetation Spectral Bio-indicators (VIs)**	3/4	in progress	EVI, NDVI	TM 5/4, 4/3 etc.	progress	
	- water, cellulose, chlorophyll, general stress	3	in progress	yes/limited	no	no	
	- nitrogen	4	in progress	no	no	yes	Local Spectral libraries and chemistry (cal/val)
	- hot spots	4	in progress	yes/limited	yes	no	
	- LST per VFC and LC	4	in progress	yes/limited	in progress	no	
III.	**Canopy function Yield (CO2 sequestration, GPP, NEP)**						
	- LUE, WUE	4	in progress		no	yes	
	- ET	4	in progress		no	yes	
IV.	**Classifications**						
1	**Fractional vegetation cover (FVC)** *[photosynthetic vegetation [PV] or non-photosynthetic vegetation [NPV], Soil]*	3	yes	no	limited		AutoMCU or equivalent (SWIR and red-edge with tied spectra)
2	**Fractional cover by plant functional type (PFTs)**	4	in progress	see below	no	yes	Required by DVGM (dynamic global vegetation models) end ESM (Earth system models); At launch 2-6 types/km^{2}, goal 6-10 resolved
V.	**Terrestrial Products Supporting Long Term Data Records**						For HyspIRI products context, and for long term records continuity
1	**MODIS Vegetation Continuous Fields (VCF - cotext &**	4	yes	yes			
	- life form (proportion of woody vegetation, herbaceous	4	yes			yes	
	- leaf type (proportion of woody vegetation that is needle	4	yes			no	
	- leaf longevity (proportion of woody vegetation that is	4	yes			no	
2	**Ecological disturbance (NPV increase)**	4	yes, global on progress	Fire product	LEDAPS		Based on PV, spectral change diagnosing disturbance type; decline/recoveery; for land history
	- Land cover conversions	4	yes, global in progress	yes	yes/limited	yes	Terrestrial ECVs: LC, permafrost, glaciers/ice, LAI, fire
	- Severe wind, deought, insect, etc.	4	in progress	yes	yes/limited	yes	False alarm a possibility
	- Fires (VISWIR detection, severity)	4	in progress	yes	yes/limited		
VI.	**Biodiversity**						
	- Optical types diversity	4	initialized	no	no	yes	see publication on the topic by Usting and Gammon
	- Plant functional diversity	4	initialized	no	no	yes	see publication on the topic by Asner, Wright, et al.
	- Biodiversity indicators	4	in progress	no	no	yes	Spectral corelation with bio-diversity

Higher Level Products for HyspIRI – Discussion Summary *(continued)*

#	Product	Level (L2/3/4)	Maturity	MODIS	Landsat	Models	Notes
C.	***Aquatic [shallow water, rivers, lakes]***						
1	Remote Sensing Reflectance (Rrs)	2 or 3	yes, operational	yes	no		Remote Sensing Reflectance = water-leaving radiance (Lw) / downwelling irradiance (Ed); (Rrs, units sr-1, 400–800 nm) ; This is the result
2	Sea Surface Temperature	2-Jan	yes, operational	yes	no		Routine product from many satellites.
3	Seafloor Spectral Reflectance (units %, 400–??? nm)	3	in progress	no	no		Combined results from aquatic retrieval
4	Water Depth	3	in progress	no	no		There are several candidate algorithms in
5	Water Optical Properties	3	in progress	yes	no		-"-
6	Retrieval Quality Flags	3	in progress	na	no		-"-
7	Fractional Cover	3	in progress	na	no		Derived from Rrs, mixture decomposition methods need scaling to HyspIRI data
8	Pigments (e.g. chlorophyll)	3	mature, work in progress to separate aquatic sources	yes	no		Derived from Rrs, work in progress to separate contributions of planktonic, submerged and emerged aquatic sources
9	Light-Use Efficiencies (for (1) Productivity and (2) Calcif	3	in progress	yes	no		There are few investigations for shallow
	- Productivity (Gross/Net)	4	in progress	yes	no		Investigations for fresh water bodies, needs synthesis of fresh, coastal and deep ocean
	- Calcification	4	not initialized	na	no		There are no existing algorithms, and there have been (virtually) no investigations
10	Water content Dissolved Organic Mater (DOM)	4	in progress	yes	no		Investigations for fresh water bodies, needs synthesis of fresh, coastal and ocean methods
11	Degree Heating Weeks	3	mature	yes	no		Routine product from many satellites.
D.	***Snow/Ice [high latitudes, high***						**Input to be obtained from:**
	Snow cover, Ice caps, Glaciers	3/4	no experts present				**Dorothy Hall, Jeff Dozier, Thomas Painter**
Top of Atmosphere and Localized Products, and By-products of Level 2 Processing							
1	TOA Optical and TIR Radiance (bands)	1B	yes	yes/limited	yes/limited		
2	Volcanoes eruption, size, prognosis	4	yes	yes/limited	yes/limited	yes	
3	Clouds (masks)	3	yes	yes	yes/limited		
4	Incident PAR (direct, diffuse PAR)	3				yes	
5	Water vapor product	3	yes			yes	
6	Aerosol optical depth product	3	yes	no	no	no	
7	Albedo	4	in progress	yes	no		