Approximately 180 scientists gathered from August 23-25, 2011 at the 4th NASA HyspIRI Science Workshop held in Washington, DC. PDF versions of the presentations given at the meeting are available from the HyspIRI website (http://hyspiri.jpl.nasa.gov).

Introduction and Meeting Overview

The HyspIRI mission was recommended for implementation by the 2007 report from the U.S. National Research Council *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (also known as the Earth Science Decadal Survey or, simply, the Decadal Survey). The annual HyspIRI workshop provides an open forum to present the observational requirements for the mission and assess its anticipated impact on scientific and operational applications; the open forum also provides an opportunity to obtain feedback from the broader scientific community on the mission concept. This year's workshop had a greater emphasis on the science applications contribution from HyspIRI and included a full day on HyspIRI related science applications for water use and availability, wildland fires, volcanology and urban and environmental studies. The morning of the first day focused on providing an overview of the mission. The afternoon of the first day focused on the use of HyspIRI data for ecosystem studies and some of the airborne precursor instrument development activities. This included a discussion of the Airborne Visible/Infrared Imaging Spectrometer Next Generation (AVIRIS-ng) as well as the airborne Hyperspectral Thermal Emission Spectrometer (HyTES). The second day was focused on science applications together with science presentations, including discussion of the science questions that HyspIRI will address. The final day included discussions of related missions, partnership opportunities and plans for 2012 and beyond. Of particular interest was the discussion of a potential airborne campaign to acquire data for both science and algorithm testing beginning in the 2012-2013 timeframe. As with previous workshops, the Preliminary Level 1 mission requirements were reviewed with the community to make sure they would meet the science needs. This year there were over 24 posters which provided an excellent opportunity for more detailed discussions between talks. The workshop participants concluded that the HyspIRI mission would provide a significant new capability to study ecosystems and natural hazards at spatial scales relevant to human resource use and would be particularly valuable for climate related studies. The participants felt the measurement requirements could be achieved with the reference instrument design concepts and be implemented through the use of current technology. The workshop participants, like the Decadal Survey itself, strongly endorsed the need for the HyspIRI mission and felt the mission, as defined, would accomplish the intended science. Workshop participants were particularly enthusiastic about a dedicated airborne

campaign as well as obtaining data from the new AVIRIS-ng and HyTES airborne sensors.

Woody Turner [NASA Hq] started the meeting by welcoming the participants and outlining the goals and objectives for this year's meeting. He then provided an update on what we have achieved so far and what was planned for the future. Woody emphasized that HyspIRI is a global mission providing full spatial resolution data (60 m) of the land and coastal regions and lower spatial resolution (1 km) data over the deeper oceans. HyspIRI will obtain full global coverage with the TIR and VSWIR sensors every 5 and 19 days respectively. Woody welcomed the members of the newly formed HyspIRI International Science Group. This group will work with current Science Study Group to evaluate potential synergies between HyspIRI and other international missions. Woody noted the opportunity for community building especially given the strong attendance at the meeting as well as previous meetings. He was particularly looking forward to hearing more about the science applications work being done for HyspIRI. He indicated the need to continue to stay focused and conduct limited risk reduction and understand which products required low latency. He closed by reiterating that HyspIRI was a global mission with a broad user community that utilized mature technologies. He indicated we need to continue to retire risks, keep costs down, build the community and develop partnerships where appropriate.

Jack Kaye [NASA Hq] followed Woody's presentation and talked about how HyspIRI fits in with the bigger inter-agency picture. Jack indicated we need to continue to focus on calibration, algorithms and validation and make sure the data provide the maximum benefit to the community. Jack noted we have had a couple of HyspIRI calls and saw these as an excellent way to demonstrate the potential of HyspIRI data using existing precursor data. He indicated how his program had been able to support several airborne instrument activities such as HyTES and AVIRIS-ng which would help the community by providing data suitable for simulating HyspIRI. Jack indicated we need continue to emphasize the value of HyspIRI-like data at the local and regional level and the societal benefits. HyspIRI is considered to be very valuable for interdisciplinary studies supported by the US Global Climate Research Program and the upcoming airborne campaign would provide valuable data for the ongoing National Climate Assessment. During the questions and answers following his talk he encouraged the use of partnerships to reduce cost.

Mike Freilich [NASA Hq] presented slightly later in the meeting due to a conflict but his comments are included here since they were of programmatic relevance. Mike started by noting that the HyspIRI launch data is currently post 2020 but that Headquarters was undertaking HyspIRI-related activities to prepare for the mission. Mike noted that there were a large number of satellites in orbit which would help to inform the next set of missions as well as several missions due to launch soon. Aquarius had just had a successful launch before the HyspIRI meeting. Mike indicated that NASA earth science had a healthy budget but the costs estimated by the Decadal Survey were considerably lower than the subsequent estimates which would affect when missions were moved into Phase A. Mike also indicated that some missions were added in to those identified by the Decadal Survey to address Administration priorities that are not in the Decadal Survey.

Currently it is expected there will be about one launch per year for the next several years. Mike emphasized the new line of Venture Class missions which includes 3 strands: 1) Airborne investigations; 2) PI-led small spaceborne missions; and 3) Instruments for future opportunities. The EV-Instrument call is expected to be yearly. Mike indicated Hq was planning to continue to fund HyspIRI studies so we understand how to keep costs down and accomplish the mission science.

Rob Green and Carl Bruce [NASA/JPL] then summarized the instrument concept for the visible shortwave infrared (VSWIR) imaging spectrometer on HyspIRI. HyspIRI will have three main payload elements, a VSWIR imaging spectrometer, a multispectral thermal infrared (TIR) imager and an Intelligent Payload Module (IPM) henceforth referred to as the VSWIR, TIR and IPM. The VSWIR imaging spectrometer will obtain data covering the spectral range from 380 to 2500 nm with 10 nm sampling. VSWIR data will be acquired over the full terrestrial surface with a 19 day revisit, including shallow water regions. The deep oceans and ice sheets also will be acquired with a 19 day revisit but resampled to a spatial resolution of 1 km. Rob noted that we have developed a set of science objectives that HyspIRI will address and provided some examples of the science that could be accomplished. This included examples ranging from the Gulf of Mexico oil spill to determining canopy nitrogen content to estimating the impact of black carbon on snow and ice melt to mapping emergent and submerged aquatic vegetation. The VSWIR instrument concept was shown to have design heritage from instruments such as the Moon Mineralogy Mapper (M3). This heritage has allowed the VSWIR instrument to be far smaller and use less power than earlier designs such as Hyperion. In-flight, the instrument would be fully calibrated with an onboard solar panel, lunar looks and ground calibration experiments. Carl noted that the current point design had remained unchanged and the mass and power were now 55kg and 41 watts respectively. Carl highlighted the importance of accuracy and calibration and that the system was both highly linear with minimal polarization sensitivity and a large swath of 145 km. Several airborne instruments have been developed which demonstrate the approach used but nonetheless the project examined alternate approaches and found they did not meet the measurement requirements. Carl noted that due to some recent detector developments only two spectrometers were required instead of the original 4 spectrometers. Carl finished by illustrating the core technologies for the VSWIR instrument and how these technologies were mature.

Simon Hook [NASA/JPL] then summarized the instrument concept for the TIR multispectral imager on HyspIRI. The TIR imager will obtain data in eight spectral channels, one of the channels is located at 4 μm and the other seven channels are located between 7 and 12 μm. TIR data will be acquired over the full terrestrial surface with a 5-day revisit, including shallow water regions. The TIR instrument operates continuously, providing both a daytime and nighttime scene for the entire earth every 5 days at the equator. The deep oceans and ice sheets also will be acquired with a 5 day revisit but resampled to a spatial resolution of 1 km. Simon presented examples of the how the TIR data would be used for a broad range of science and applications with particular emphasis on volcanoes, wildfires, and water use and availability. For each area, Simon provided examples of how the instrument concept was designed to address critical questions in

these areas. Simon showed how the revisit will be greater at higher latitudes and used an example from the recent Iceland eruption to highlight how the TIR would have been able to provide daily information on the composition and chemistry of the volcanic plume, of particular importance for aeronautics. The TIR instrument concept has design heritage from instruments such as ASTER and MODIS and is a mature concept that can be built and launched in the same timeframe as the VSWIR instrument. Simon highlighted risk reduction activities underway for the TIR including science risk reduction associated with the development of the HyTES and instrument risk reduction associated with the development of the Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR). PhyTIR is a laboratory demonstration of key instrument capabilities including the focal plane assembly and scanning mechanism. HyspIRI-TIR data will be collected with a 2-sided scan mirror. The dwell time for any given pixel will be 32 microseconds. The system will use a Mercury Cadmium Telluride detector and the focal plane will be cooled to 60 Kelvin with an active cooler. A two point calibration (blackbody and deep space view) will be performed every 2 seconds. There also will be lunar looks and ground calibration using automated validation sites. The system will use a Cassegrain telescope with radiation from the instrument baffled away from the detector. There will be a single detector array, having 32 readout ports, with 256X16 pixels in each of the 8 spectral channels. The system will use time-delay-and-integration with each channel using 4 columns from the array; since each channel has extra columns, the best 4 columns can be used. Current testing of a prototype read out integrated circuit indicates compliance with noise and power specifications, and the instrument noise equivalent temperature difference should be less than 0.2 K in the seven thermal infrared channels, with ample signal from hot targets for the mid infrared channel. As part of the PHyTIR activity detector material will be added to the ROIC and tested with a scan mirror operating at the same speed as the spaceborne instrument. Various commercial cryocoolers are being studied with several available that meet the design requirement Simon closed by restating the TIR will provide essential data for reducing the uncertainties in land carbon flux together with data for a range of applications from volcano monitoring to wildfires.

Scott Ollinger [University of New Hampshire] presented the first science keynote on "Vegetation canopies in a whole new light: Measurements for New Understanding of the Earth's Carbon Cycle and Ecosystem-Climate Feedbacks". Scott noted that plants process 15-20% of atmospheric carbon dioxide annually and are among the largest processors of carbon globally. Scott showed how the carbon and nitrogen cycles are linked and, to fully understand the carbon cycle, you also need to understand the nitrogen cycle. For example plant nitrogen concentrations help control both photosynthesis and respiration and in temperate deciduous regions, nitrogen is a more important driver of canopy photosynthesis than leaf area index. HyspIRI will enable the nitrogen in canopies to be mapped, a capability that is not currently available at broad spatial scales. The metabolism of plants and ecosystems is increasingly well understood at the local scale, but the lack of corresponding data at the global scale means there are still large uncertainties in future CO2/climate predictions. Many land models do not include the nitrogen cycle and those that are working to incorporate it are limited by a lack of data on vegetation nitrogen status over broad scales. Despite these limitations, well calibrated imaging spectrometer data can be used to predict nitrogen response in plants and Scott is

currently using airborne data to test relationships over a wide range of sites in the Ameriflux network. The airborne data are at higher spatial resolutions than future HyspIRI data, but when resampled to HyspIRI resolution provide similar results. Scott noted our ability to characterize vegetation globally and its role in the carbon/climate system is limited and has been for decades. The role of the nitrogen cycle and vegetation nitrogen status represents a long-standing constraint. Global, high-resolution, high fidelity imaging spectrometer data will reduce substantially uncertainties in terrestrial carbon metabolism. Full spectral data may also help to reveal new processes that are unrecognized or presently underappreciated, and can also help to provide stepping stones between detailed field measurements and coarser resolution global data sets.

Bogdan Oaida [NASA/JPL] discussed the overall mission concept. HyspIRI is optimized to operate in a 626 km Sun synchronous orbit with a 10:30 am descending equatorial crossing time. Bogdan showed there are several other potential orbits that could support the 19-and 5-day revisit of the VSWIR and TIR respectively, including an orbit around 705 km used by many other spacecraft. Bogdan outlined the operations concept for HyspIRI which is very simple since both instruments are always turned on in order to provide global mapping. The VSWIR data are day-only and currently planned to be acquired when the local solar elevation is greater than 20 degrees, however, this constraint may be relaxed to 10 degrees to provide additional coverage in the Polar Regions. The HyspIRI payload can be accommodated by a number of commercially available spacecraft buses, some of which may require modifications to the power generation system to meet mission needs. Additional upgrades will likely include a solid state recorder with a 1 Tb capacity. HyspIRI is continuing to maintain compatibility with several Launch Vehicles, including the possibility of a shared launch. The ground systems and data management concept continues to be matured. As part of that effort and in a response to a Request For Information, KSAT has indicated they will have ample capacity to meet the downlink needs of HyspIRI with two polar downlink stations operating in the X-Band spectrum. The two polar stations are at Svalbard and Poker Flat, with additional stations available at both poles if needed.

Dan Mandl [NASA/GSFC] described the IPM. The IPM will provide low latency data which can be used for a wide range of applications such as near realtime monitoring of fires or floods. There will be two data streams on the spacecraft; one is downloaded through the normal route while a second identical stream goes to the IPM. The IPM will be able to subset and process this second stream and download the data in near realtime (NRT) via a direct broadcast antenna. The NRT data will be available over the internet. Work is currently underway benchmarking the Computer Processing Unit for IPM and developing delay tolerant network communication connectivity to handle any network disruption. The web coverage service will be used to automatically load algorithms so a custom algorithm can be loaded for a particular task or application and the data downloaded in NRT such as during a fire or flood. An IPM testbed for HyspIRI has been developed and is being used for testing algorithms such as automated atmospheric correction using existing Hyperion data.

Rob Green [NASA/JPL] and Simon Hook [NASA/JPL] then reviewed the Draft Level 1 Mission Requirements which serve as the top-level requirements for the HyspIRI mission and provide the basis for deriving the more detailed Level 2 requirements. These requirements were first presented at the 2008 Workshop and are reviewed at each workshop to make sure the community is fully aware of the data that HyspIRI will provide.

Jose Moreno [University of Valencia, Spain] then gave the second science keynote on the unique role for HyspIRI in Earth System Science Dynamical Global Vegetation Models. Jose began by summarizing the background and motivation for the presentation and then described the status of dynamical vegetation models and uniqueness of HyspIRI data. This was followed by a discussion of the different approaches for incorporating ecosystem information in the models. Currently three approaches are used: 1) assigned fixed tables of biophysical variables to classification maps, 2) retrieval of biophysical variables as direct inputs to a model and 3) direct assimilation of radiances/reflectances into the models. Finally Jose provided his perspectives on current trends and the way forward. Jose noted that we are now moving away from assigned biophysical variables for fixed vegetation types, obtained through approaches like land classification, towards the direct inputs to models of retrieved biophysical variables. Many of the key variables required can be obtained by a combination of visible to shortwave infrared imaging spectrometer data and thermal infrared data as will be provided by HyspIRI. Global data are available but the low spatial resolution and limited spectral information only allow indirect observation of the dynamical vegetation processes. HyspIRI will provide systematic global sampling at the appropriate spatial and spectral resolutions and complete spectral coverage. The key problem right now is the large number of parameters and large uncertainty in such parameters, which is limiting our ability to run predictive analyses based on perturbation of free model parameters to test future climate scenarios. We can undertake model intercomparisons to optimize existing parameterizations and limit parameter space but we need a reference dataset which is global, high spatial resolution and spectrally complete with good temporal resolution and covering several seasonal cycles – HyspIRI will provide that dataset.

Science Presentations

After the two keynote presentations the remainder of the first day, all of the second day and part of the third day was devoted to science and science applications talks. There were over 40 talks and most of the presentations associated with these talks are available from the HyspIRI website. The talks covered a wide range in topics and included updates from the studies funded by NASA solicitations as well as updates on the key science questions that HyspIRI will address. The science questions were developed in conjunction with the Science Study Group, a group of scientists appointed by NASA to help guide the mission and ensure the measurements are of maximum benefit. The science talks on the second day were dedicated to the use of HyspIRI data in science applications. The science applications talks covered many areas including water use and availability, wildland fires, volcanology and urban and environmental studies. The early part of the third day included several engineering presentations on the Intelligent Payload Module (IPM). The IPM includes onboard processing combined with direct broadcast

and will be available for a subset of the data. The remainder of the third day included both science talks as well as presentations from our international and domestic colleagues on related programs, for example the National Science Foundation supported NEON program.

Review of the Workshop and Next Steps

The final presentation reviewed the progress since the last meeting and future activities. Woody Turner began the wrap-up by commenting that not only was the workshop a wonderful series of talks on the utility of visible shortwave infrared imaging spectrometer data and multispectral thermal infrared imagery but more importantly a demonstration of the fundamental ground breaking science that could be performed by the combined capability from both instruments. Further, the Applications day had clearly demonstrated the value of the data for use in operational systems. Participants noted the large number of posters displayed at the meeting and asked that future meetings include an evening session dedicated to the posters. Of particular interest with the community was the possibility of an airborne campaign in California using the AVIRIS and MASTER sensors to acquire HyspIRI-like datasets for science development. Potential flight corridors were discussed together with how to ensure the necessary field measurements were made to maximize the usefulness of the data. There was also considerable interest in the follow-on airborne instruments AVIRIS-NG and HyTES and participants were eager to see data from both instruments at the next meeting. Lastly participants welcomed the greater international participation and are looking forward to additional presentations from the international community especially through the newly formed International Science Group.

In summary, the participants felt that the HyspIRI mission would provide a significant new capability to study ecosystems and natural hazards at spatial scales relevant to human resource use. The participants confirmed the Draft Preliminary HyspIRI Mission Level 1 Requirements were achievable within the mission concept presented and would provide the necessary data to address the science questions identified for the mission.