EO-1/HYPERION: NEARING TWELVE YEARS OF SUCCESSFUL MISSION SCIENCE OPERATION AND FUTURE PLANS

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1. INTRODUCTION

The Earth Observing One (EO-1) satellite is a technology demonstration mission that was launched in November 2000, and by July 2012 will have successfully completed almost 12 years of high spatial resolution (30 m) imaging operations from a low Earth orbit. EO-1 has two unique instruments, the Hyperion and the Advanced Land Imager (ALI). Both instruments have served as prototypes for NASA's newer satellite missions, including the forthcoming (in early 2013) Landsat-8 and the future Hyperspectral Infrared Imager (HyspIRI). As well, EO-1 is a heritage platform for the upcoming German satellite, EnMAP (2015). Here, we provide an overview of the mission, and highlight the capabilities of the Hyperion for support of science investigations, and present prototype products developed with Hyperion imagery for the HyspIRI and other space-borne spectrometers.

2. THE HYPERION IMAGING SPECTROMETER

The Hyperion has demonstrated the viability and value of satellite-based imaging spectroscopy from a low earth orbit. Hyperion covers the 0.4 to 2.5 μm range with 242 overlapping spectral bands (196 of which are well calibrated) at approximately 10 nm spectral resolution and 30 m spatial resolution, and can image a 7 km x 100 km land area per image. Currently, the stability of the Hyperion measurements is within ±1.5%, with a "moderate fidelity". Hyperion data have a lower SNR (~ 160:1, 0.4-1.0 μm; ~ 40:1, 1.0-2.5 μm) as compared to the current "Classic" Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-Classic), but its SNR is comparable to that for data obtained with the original 1995 AVIRIS sensor [1]. As of early 2012, there have been over 54,000 scenes of both Hyperion and ALI imagery collected around the world. The 2011 collections are shown in **Fig. 1**. and archived at the USGS EROS Data Center. The full spectrum and relatively narrow spectral resolution of the Hyperion has enhanced the development of passive Earth remote sensing techniques, and enabled significant advances in detecting land surface categories and vegetation properties due to improved accuracy when used with spectral classifiers. The Hyperion imagery also demonstrated that heat emission from some important Earth processes (e.g. lava flows and wildfires) can be measured using data in the 0.4 - 2.5 μm range, i.e. without the need of a thermal instrument.

Science and Applications for Ecosystems

Here, we highlight the use of Hyperion data for ecosystem and vegetation information retrieval and use. For example, Hyperion imagery have proven successful in discriminating land cover types, species mapping, and for deriving Vegetation Indices. Bio-physical products have emerged for forest canopy nitrogen, primary production, LAI and vegetation canopy closure, vegetation fractional cover, as well as canopy greenness, wetness and

pigment content. An example of an ecosystem product developed by the EO-1 Project is provided in **Fig. 2**. A partial list of cited literature is provided here, showing that Hyperion data have successfully been utilized for many forest related studies [1-11], as well as agriculture, pastures, savannas, and wetlands [12-18]. Special topics address nitrogen content [19-21], invasive species [22-23], ecosystem fragmentation [24-25], and tower fluxes [26]. Many studies investigated cross sensor capabilities [27,3,5,10,22,24] and new hyperspectral methods [9,11,28]. A complete list of EO-1 publications can be viewed at the EO-1 web site (http://eo1.gsfc.nasa.gov/new/ SeniorReviewMaterial_References.doc).

3. SUMMARY

The EO-1 mission has exceeded its primary goals to enable more effective (and less costly) hardware and data strategies for Earth science orbital missions in the 21st century. Both the Hyperion and ALI have paved the way for future, essential Earth observing satellite missions.

11. REFERENCES

[1] Asner, G. P., D. Nepstad, G. Cardinot, and D. Ray, "Drought stress and carbon uptake in an Amazon forest measured with spaceborne imaging spectroscopy", *Proceed. Nat'l Acad. Sci.*, vol. 101, pp. 6039-6044, 2004.

[2] Asner, G.P., "Hyperspectral remote sensing of canopy chemistry, physiology and diversity in tropical rainforests", In Hyperspectral remote sensing of tropical and subtropical forests, M. Kalacska and G.A. Sanchez-Azofeifa (eds.) Taylor and Francis, Chapter 12, 2008.

[3] Foster, J., R. Philip, A. Townsend, and C.E. Zganjar, "Spatial and temporal patterns of gap dominance by low-canopy lianas detected using EO-1 Hyperion and Landsat Thematic Mapper", *Rem. Sens. Environ.,* vol. 112, pp. 2104-2117, 2008.

[4] Kalacska, M., G.A. Sanchez-Azofeifa, B. Rivard, T. Caelli, H.P. White, J.C. Calvo-Alvarado, "Ecological fingerprinting of ecosystem succession: Estimating secondary tropical dry forest structure and diversity using imaging spectroscopy", *Rem. Sens. Environ.*, vol. 108, pp. 82-96, 2007.

[5] Kim, Y., A. Huete, Z. Jiang, and T. Miura, "Multisensor reflectance and vegetation index comparisons of Amazon tropical forest phenology with hyperspectral Hyperion data", *Rem. Sens. Model. Ecosys. for Sustainability IV,* vol. 6679, 2007.

[6] Thenkabail, P. S., E.A. Enclona, M.S. Ashton. C. Legg, and M.J. De Dieu, "Hyperion, IKONOS, ALI, and ETM+ sensors in the study of African rainforests", *Rem. Sens. of Environ.,* vol. 90, 23-43, 2004.

[7] Townsend, P.A. and J.R. Foster, "Comparison of EO-1 Hyperion to AVIRIS for mapping forest composition in the Appalachian Mountains, USA", *Geosci. Rem. Sens. Symposium*, vol. 24-28, pp. 793- 795, 2002.

[8] Townsend, P.A., "Application of imaging spectroscopy to mapping canopy nitrogen in the forests of the Central Appalachian Mountains using Hyperion and AVIRIS", *IEEE Trans. Geosci. Rem. Sens.,* vol. 41, p. 1347, 2003.

[9] Pu, R. and P. Gong, "Wavelet transform applied to EO-1 hyperspectral data for forest LAI and crown closure mapping", *Rem. Sens. Environ.,* vol. 91, pp. 212–224, 2004.

[10] Pu, R., P. Gong, and Q. Yu, "Comparative analysis of EO-1 ALI and Hyperion, and Landsat ETM+ data for mapping forest crown closure and leaf area index", *Sensors*, vol. 8, pp. 3744-3766, 2008.

[11] Zeng, Y., M.E. Schaepman, B. Wu, J.G.P.W. Clevers, and A.K. Bregt, "Forest structural variables retrieval using EO-1 Hyperion data in combination with linear spectral unmixing and an inverted geometric-optical model", *J. Rem. Sens. - Special Issue of ISPMSRS05*, vol. 11, 2008.

[12] Rao, N., Rama, P.K. Garg, and S.K. Ghosh, "Evaluation of radiometric resolution on land use/land cover mapping in an agricultural area," *Internat'l J. Rem. Sens.,* vol. 28, pp. 443-450, 2007.

[13] Bannari, A., M. Chevrier, K. Staenz and H. McNairn, "Potential of hyperspectal indices for estimating crop residue cover", *Revue Télédétection*, vol. 7, pp. 447-463, 2008.

[14] Datt, B., D.L.B. Jupp, T. McVicar, T. Van Niel, and J. Pearlman, "Time Series Analysis of EO-1 Hyperion Data for Crop Identification and Yield Estimation at an Agricultural Site," *IEEE International Geosci. Rem. Sens. Symposium*, 2003.

[15] Galvão, L.S., D.A. Roberts, A. R. Formaggio, I. Numata, and F.M. Breunig, "View angle effects on the discrimination of soybean varieties and on the relationships between vegetation indices and yield using off-nadir Hyperion data", *Rem. Sens. Environ.,* vol. 113, pp. 846-856, 2009.

[16] Guerschman, J.P., M.J. Hill, L.J. Renzullo, D.J. Barrett, A.S. Marks, and E.J. Botha, "Estimating fractional cover of photosynthetic vegetation, non-photosynthetic vegetation and bare soil in the Australian tropical savanna region upscaling the EO-1 Hyperion and MODIS sensors", *Rem. Sens. Environ.,* vol. Xx, pp. Xxx-xxx, 2009.

[17] Mobasheri, M.R., Y. Rezaei, M.J. Valadan, and A. Zoej, "Method in extracting vegetation quality parameters using Hyperion images, with application to precision farming", *World Appl. Sci. J.,* vol. 2, pp. 476-483, 2007.

[18] Zhang, J., K. Staenz, P.R. Eddy, N. Rochdi, D. Rolfson, and A.M. Smith, "Analysis of spaceborne Hyperion imagery for the estimation of fractional cover of rangeland ecosystems", *The Internat'l Archives Photogramm., Rem. Sens. and Spatial Information Sci.,* vol. XXXVII, part B7, 2008.

[19] Martin, M.E., L.C. Plourde, S.V. Ollinger, M.L. Smith, and B.E. McNei, "A generalizable method for remote sensing of canopy nitrogen across a wide range of forest ecosystems", *Rem. Sens. Environment,* vol. 112, pp. 3511-3519, 2008.

[20] McNeil, B.E., J.M. Read, T.J. Sullivan, T.C. McDonnell, I.J. Fernandez, and C.T. Driscoll, "The spatial pattern of nitrogen cycling in the Adirondack Park, New York", *Ecolog. Appl.,* vol. 18, pp. 438–452, 2008.

[21] Ollinger, S.V., A.D. Richardson, M.E. Martin, D.Y. Hollinger, S.E. Frolking, P.B. Reich, L.C. Plourde, G.G. Katul, J.W. Munger, R. Oren, M.-L. Smith, K.T. Paw Ug, P.V. Bolstad, B.D. Cook, M.C. Day, T.A. Martin, R.K. Monson, and H.P. Schmid, "Canopy nitrogen, carbon assimilation, and albedo in temperate and boreal forests: Functional relations and potential climate feedbacks", *Proceedings of the National Academy of Sciences,* vol. 105,*pp.* xxx, 2008.

[22] Walsh, S.J., A.L. McCleary, C.F. Mena, Y. Shao, J.P. Tuttle, A. González, and R. Atkinson, "QuickBird and Hyperion data analysis of an invasive plant species in the Galapagos Islands of Ecuador: Implications for control and land use management"' *Rem. Sens. Environ.,* vol 112, pp. 1927–1941, 2008.

[23] White, J. C., N.C. Coops, T. Hilker, M.A. Wulder, and A.L. Carroll, "Detecting mountain pine beetle red attack damage with EO-1 Hyperion moisture indices", *Internat'l J. Rem. Sens.,* vol. 28, pp. 2111-2121, 2007.

[24] Brown, H.E., M.A. Diuk-Wasser, Y. Guan, S. Caskey and D. Fish., "Comparison of three satellite sensors at three spatial scales to predict larval mosquito presence in Connecticut wetlands", *Rem. Sens. Environ.,* vol. 112, pp. 2301-2308, 2008.

[25] Pignatti, S., R.M. Cavalli, V. Cuomo, L. Fusilli, S. Pascucci, M. Poscolieri, and F. Santini, "Evaluating Hyperion capability for land cover mapping in a fragmented ecosystem: Pollino National Park, Italy," *Rem. Sens. Environ.,* vol. 113, pp. 622-634, 2009.

[26] Huete, A.R., T. Miura, Y. Kim, K. Didan, and J. Privette, "Assessments of multi-sensor vegetation index dependencies with hyperspectral and tower flux data", *Rem. Sens. Modeling of Ecosystems for Sustainability III*, vol. 6298, 629814, 2006.

[27] Miura, T., A.R. Huete, and H. Yoshioka, "An empirical investigation of cross-sensor relationships of NDVI and red/near-infrared reflectance using EO-1 Hyperion data", *Rem. Sens. Environ.,* vol. 100, pp. 223-236, 2006.

[28] Mobasheri, M.R., Y. Rezaei, M.J. Valadan, and A. Zoej, "Method in extracting vegetation quality parameters using Hyperion images, with application to precision farming", *World Appl. Sci. J.,* vol. 2, pp. 476-483, 2007.
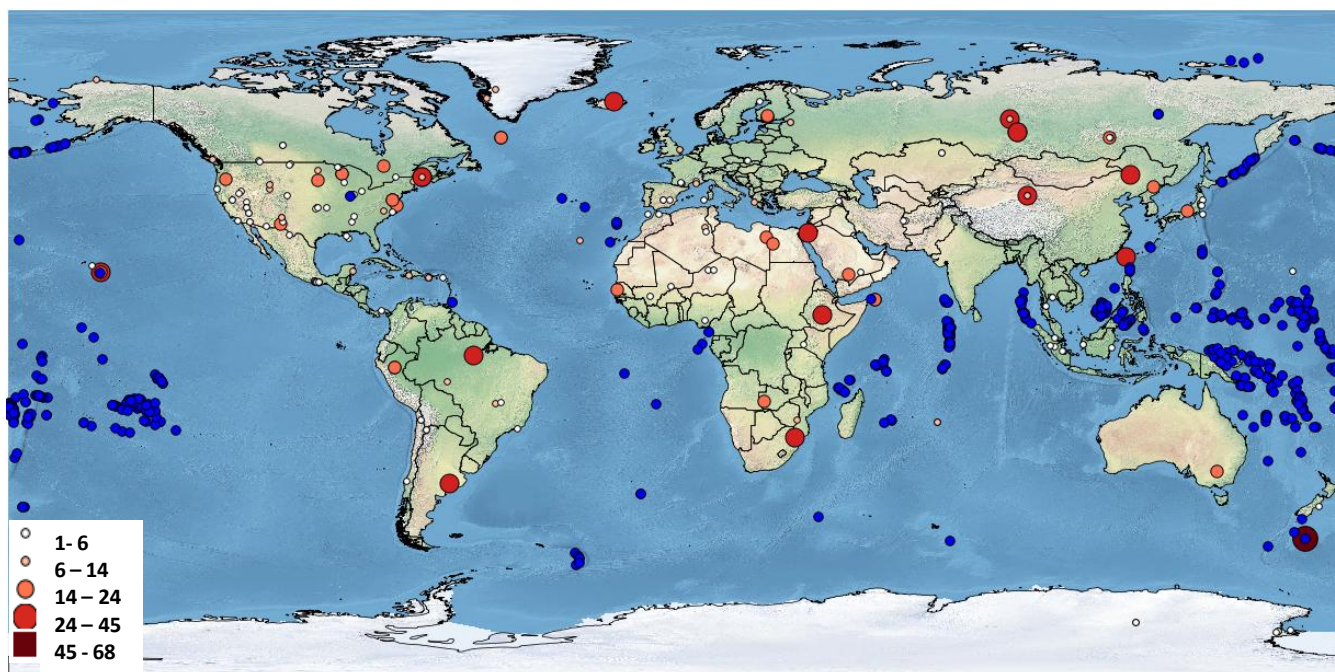
Figure 1: *EO-1 Hyperion Collections during 2011 (successful relative to requests).*
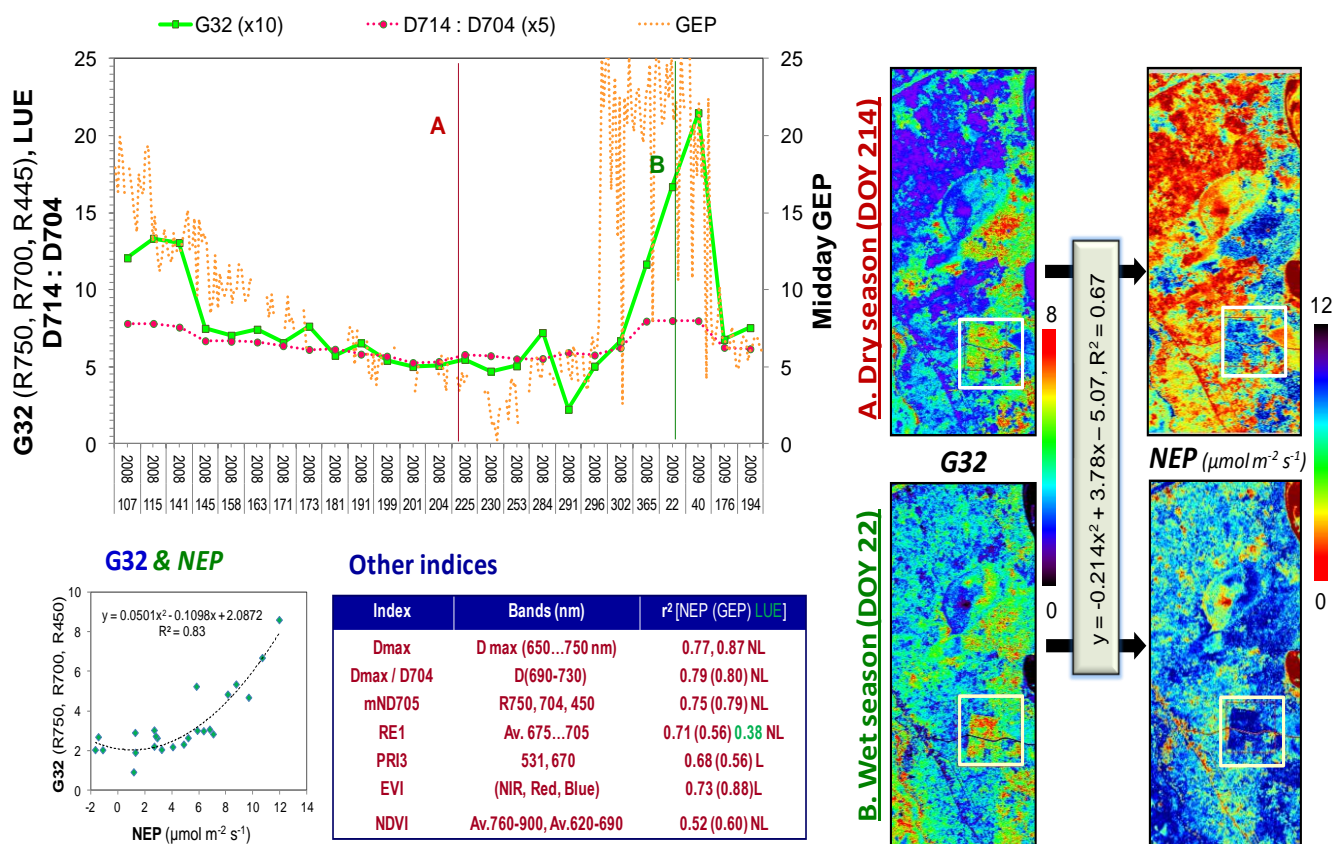

Index	Bands (nm)	r² [NEP (GEP) LUE]
Dmax	D max (650...750 nm)	0.77, 0.87 NL
Dmax / D704	D(690-730)	0.79 (0.80) NL
mND705	R750, 704, 450	0.75 (0.79) NL
RE1	Av. 675...705	0.71 (0.56) 0.38 NL
PRI3	531, 670	0.68 (0.56) L
EVI	(NIR, Red, Blue)	0.73 (0.88)L
NDVI	Av.760-900, Av.620-690	0.52 (0.60) NL

Figure 2: *Remote sensing results are shown for EO-1/Hyperion vs. mid-day CO_2 fluxes at a flux tower site in Mongu, Zambia in Africa. A spectral bio-indicator associated with chlorophyll content, G32 (using bands at 750, 700, and 445 nm), best captured the CO_2 dynamics related to ecosystem phenology over 3 years (2008-2010).*