Enhanced Very High Resolution (EVHR) products API for Earth Science

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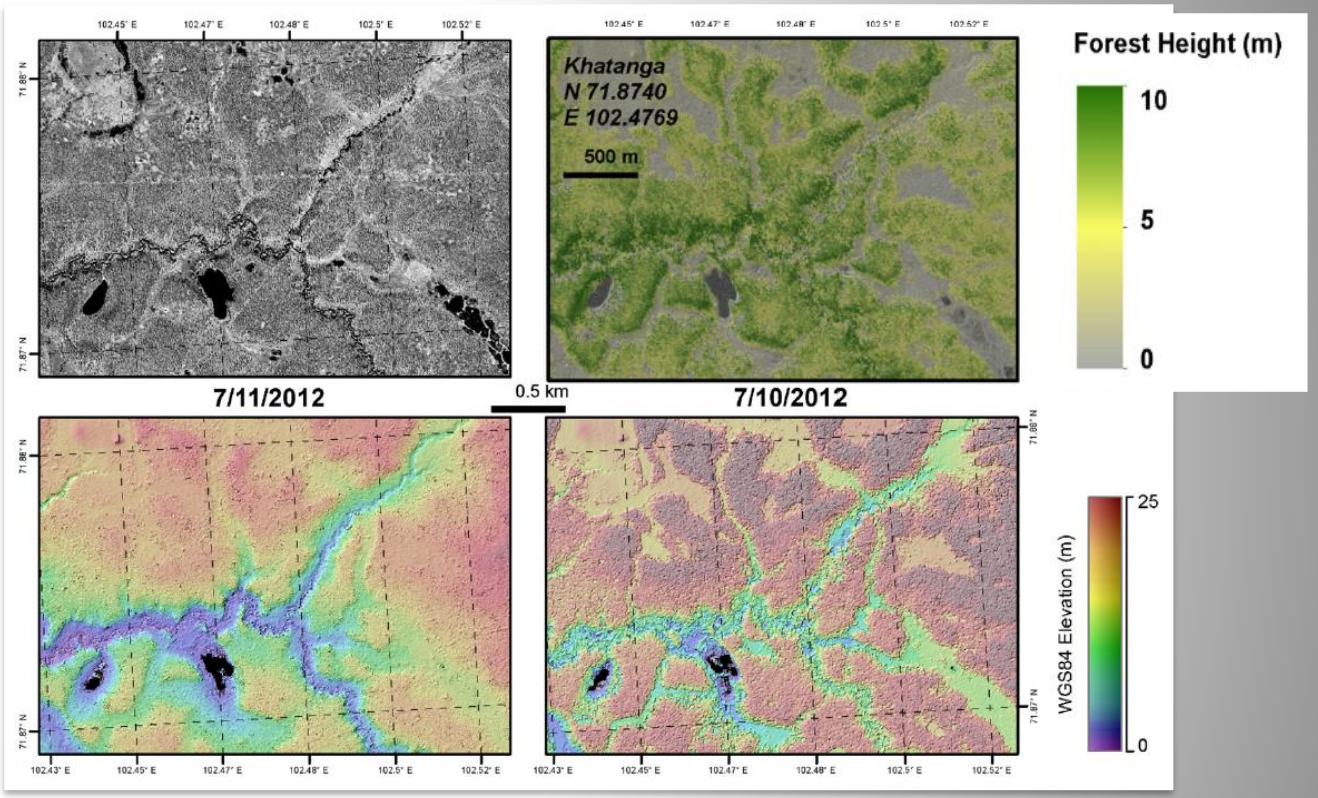


Panchromatic WV imagery with corresponding color day-apart shaded relief DSMs of the same location from stereo pair acquisitions taken with different sun elevation angles. ©DigitalGlobe NextView 2012 Montesano, Neigh et al. RSE 2017

Outline

1) **Overview of the NASA Enhanced Very-High Resolution (EVHR) products, ADAPT API**
   - Current status of access to DigitalGlobe data “NGA Nextview/NASA Databuy”
   - Scientist needs for commercial sub-meter data products
   - Science products derived from the API

2) **Examples of how derived products are used in Earth Science (brief literature review)**
   - Terrestrial ecology
   - Cryospheric sciences
   - Hydrology
   - Training data for thematic mapping classification algorithms
   - Validation/site characterization

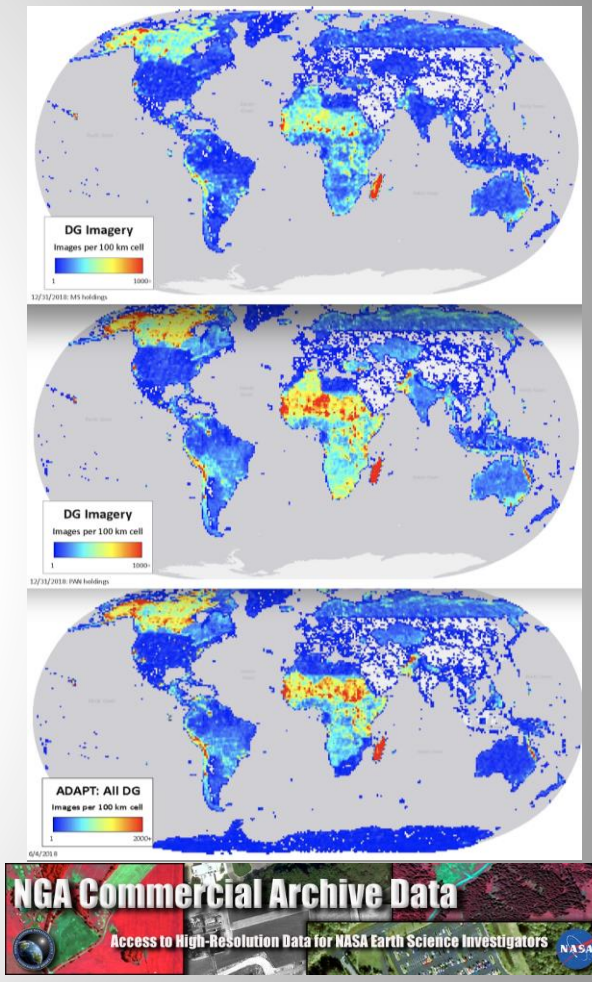
Background / Abstract Cont.

From PI-Neigh's 9 years of experience in delivering these data to NASA funded PI's, these three reasons create a bottleneck that impedes two common uses of these data:

1) individual scenes for evaluation and validation of coarser resolution NASA EO products; and

2) analyses of VHR scenes to quantify environmental phenomena with object-based classification or 3D-reconstruction from one of many individual VHR scenes.

The target audience is broadly the community of NASA-funded Earth scientists, specifically scientists funded through ABoVE, HiMAT, and registered users of cad4nasa.gsfc.nasa.gov. Access to the VHR data is limited to NASA-funded researchers so we are targeting the ABoVE and HiMAT communities that are already users of the ADAPT system.



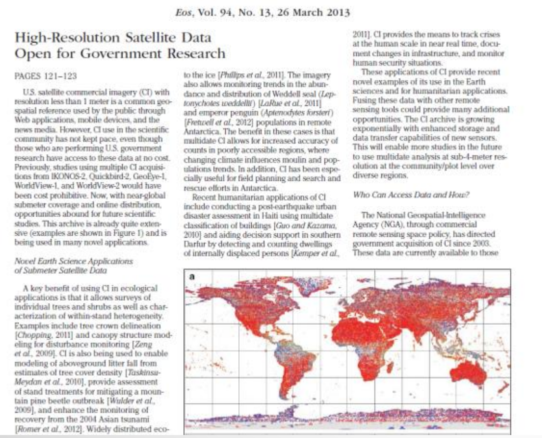
Density Maps of ADAPT VHR data holdings from Co-I Slayback

> 4 Petabytes, > 5.5 million images

Background - Why is an API needed?

Commercial Data Status

1. The volume of commercial sub-meter remotely sensed data is growing at rates exceeding petabytes per year and the costs for data storage systems and computing have both dropped exponentially.
2. US federal contracts and licensing agreements with DigitalGlobe has opened the door for "Big Data" processing to characterize land surface phenomena in HEC environments yet integration into NASA Earth Science has been slow (Neigh *et al.* 2013).



Eos, Vol. 94, No. 13, 26 March 2013

High-Resolution Satellite Data Open for Government Research

PAGES 121–123

U.S. satellite commercial imagery (CI) with resolution less than 1 meter is a common geospatial reference used by the public through Web applications, mobile devices, and the news media. However, CI use in the scientific community has not kept pace, even though those who are performing U.S. government research have access to these data at no cost. Previously, studies using multiple CI acquisitions from IKONOS-2, Quickbird-2, GeoEye-1, WorldView-1, and WorldView-2 would have been cost prohibitive. Now, with near-global submeter coverage and online distribution, opportunities abound for future scientific studies. This archive is already quite extensive (examples are shown in Figure 1) and is being used in many novel applications.

Novel Earth Science Applications of Submeter Satellite Data

A key benefit of using CI in ecological applications is that it allows surveys of individual trees and shrubs as well as characterization of within-stand heterogeneity. Examples include tree crown delineation [*Chopping*, 2011] and canopy structure modeling for disturbance monitoring [*Zeng et al.*, 2009]. CI is also being used to enable modeling of aboveground litter fall from estimates of tree cover density [*Taskinsu-Meydan et al.*, 2010], provide assessment of stand treatments for mitigating a mountain pine beetle outbreak [*Wulder et al.*, 2009], and enhance the monitoring of recovery from the 2004 Asian tsunami [*Romer et al.*, 2012]. Widely distributed eco-

to the ice [*Phillips et al.*, 2011]. The imagery also allows monitoring trends in the abundance and distribution of Weddell seal (*Leptonychotes weddellii*) [*LaRue et al.*, 2011] and emperor penguin (*Aptenodytes forsteri*) [*Frenzell et al.*, 2012] populations in remote Antarctica. The benefit in these cases is that multidate CI allows for increased accuracy of counts in poorly accessible regions, where changing climate influences moulin and populations trends. In addition, CI has been especially useful for field planning and search and rescue efforts in Antarctica.

Recent humanitarian applications of CI include conducting a post-earthquake urban disaster assessment in Haiti using multidate classification of buildings [*Guo and Kazama*, 2010] and aiding decision support in southern Darfur by detecting and counting dwellings of internally displaced persons [*Kemper et al.*, 2011]. CI provides the means to track crises at the human scale in near real time, document changes in infrastructure, and monitor human security situations.

These applications of CI provide recent novel examples of its use in the Earth sciences and for humanitarian applications. Fusing these data with other remote sensing tools could provide many additional opportunities. The CI archive is growing exponentially with enhanced storage and data transfer capabilities of new sensors. This will enable more studies in the future to use multidate analysis at sub-4-meter resolution at the community/plot level over diverse regions.

Who Can Access Data and How?

The National Geospatial-Intelligence Agency (NGA), through commercial remote sensing space policy, has directed government acquisition of CI since 2003. These data are currently available to those

Neigh et al. 2013 EOS

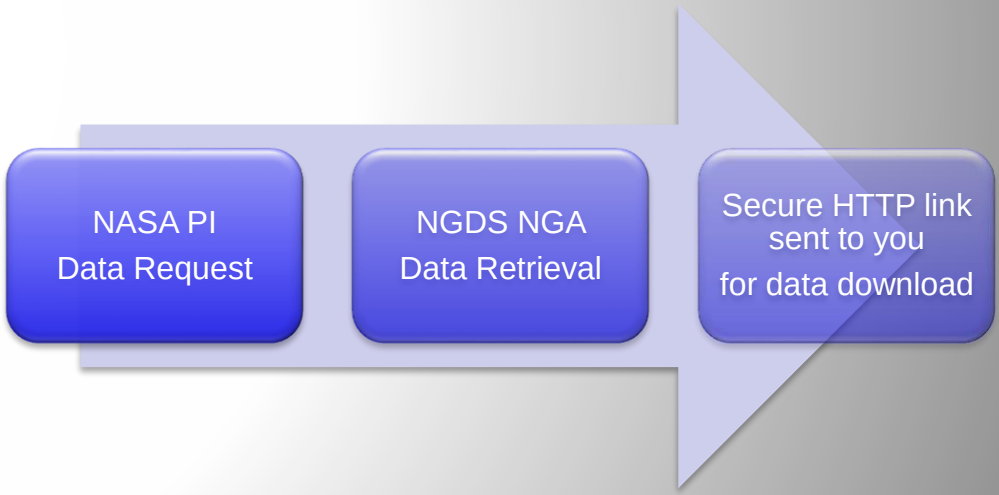
Data sourced from the US DOD are difficult to use by Earth scientists for 3 main reasons:

1. most of the very high-resolution (VHR) data received at NASA-GSFC are not in a standard, GIS-ready format, they come in Department of Defense (DOD) National Imagery Transit Format (NITF);
2. the raw data have poor horizontal and vertical co-registration; and
3. once ortho'd GeoTiffs are produced the data can have large file sizes (~5 Gigabytes for an individual image at 0.3 m to 30+ Gigabytes for a strip of those images) and require HEC environments to process and analyze many images in an efficient manner.

NPP VIIRS

Access has been provided via NGA to archived DigitalGlobe imagery for use in NASA-funded research

- The National Geospatial-Intelligence Agency's (NGA's) extensive archive of commercial satellite data are available federally-funded users free of direct cost.
- We manage data acquisition for these users, many of whom are university affiliates without access to interfaces such as NGDS.
- Users register on our site, we verify NASA grant information for non-NASA users, provide license information and a data use agreement. Users are provided passwords that allow for data request submission, which we fill once signed DUAs are provided.
- Currently: 340+ registered users, over 9 years we have fielded > 500 user requests that have resulted in > 60 publications.



DigitalGlobe U.S. Gov. Data Licensing and Copyrights

NextView License

- U.S. Government including all branches, departments, agencies, and offices
- Temporary Licensed Users :
  - State Governments
  - Local Governments
  - Foreign Governments and inter-governmental organizations
  - NGO's and other non-profit organizations

All high-resolution commercial satellite imagery purchased by NGA is NextView licensed.

USG may provide the imagery to the above organizations when collaborating on an official purpose.

More information available here: https://cad4nasa.gsfc.nasa.gov/images/NGA-NextView-License.png

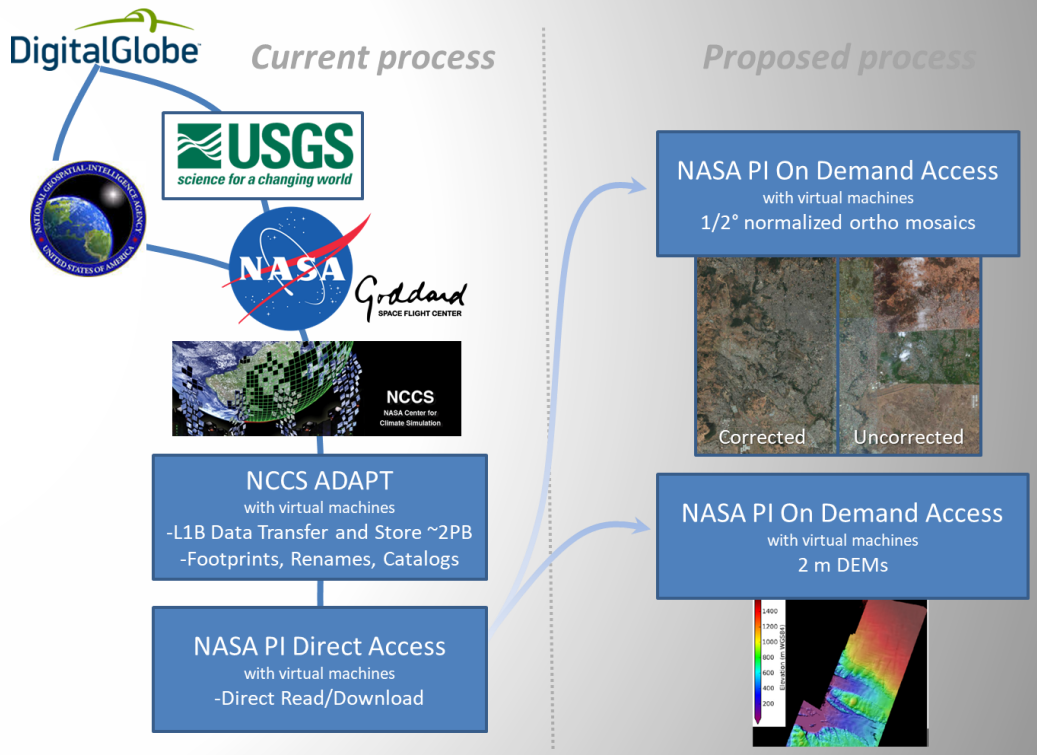
Objectives

Our work seeks to provide tools as an Application Program Interface (API) for mass processing spatially contiguous and temporally consistent archived NASA-GSFC DG VHR data that can only efficiently be performed on NASA HEC resources due to DG-NGA licensing limitations and computational requirements.

Our objectives are to:

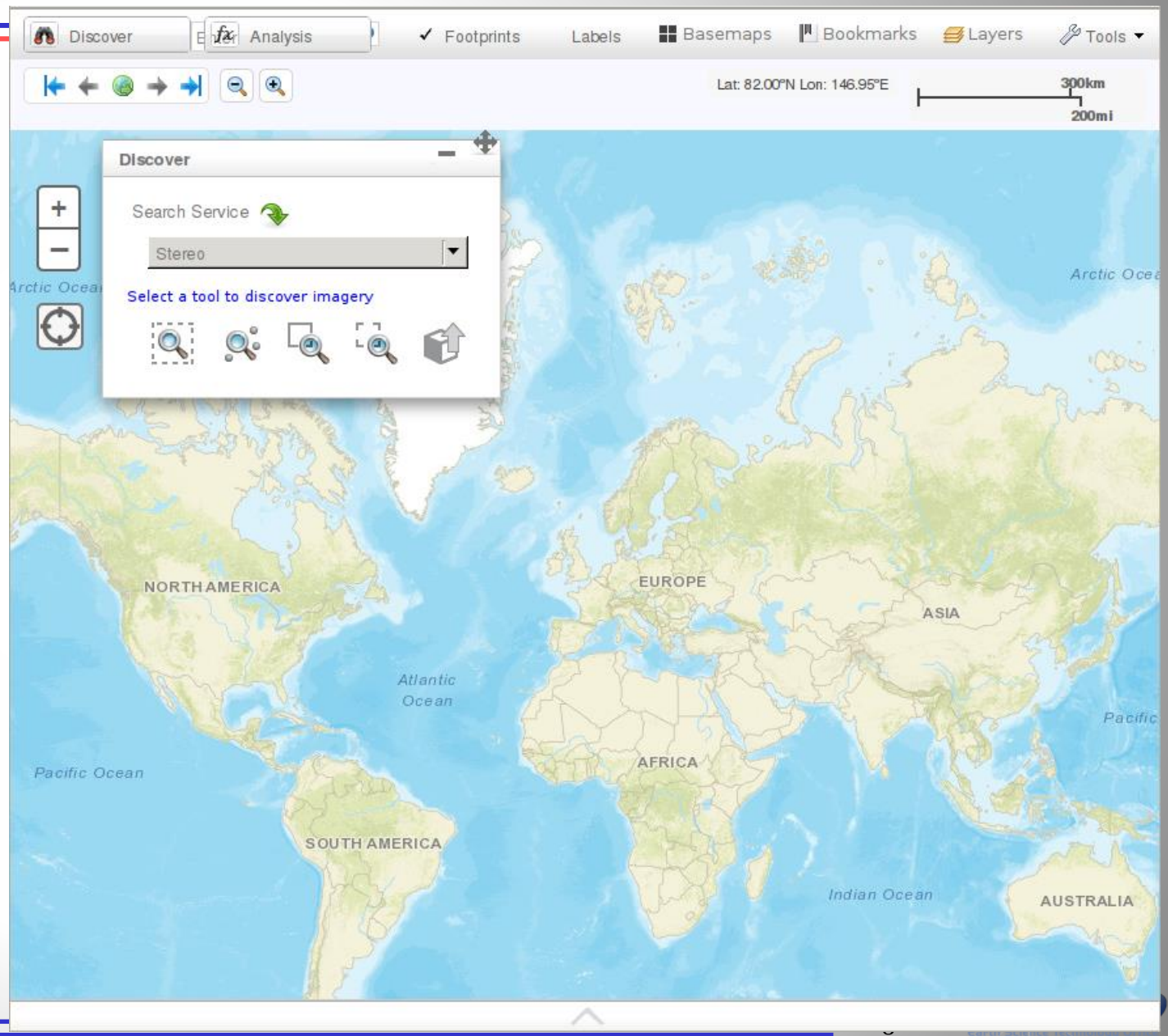
1. **Improve VHR data querying:** using databases and ArcGIS mosaic datasets within NASA-GSFC's ADAPT global archive of DG VHR imagery;
2. **Produce on demand VHR regional mosaics:** automating estimates of surface reflectance, ortho-rectifiying and normalizing 1 m mosaics for pan and 2 m for multi-spectral; and
3. **Produce on demand 4 m posting DEMs:** leveraging HEC processing and open source NASA-Ames software.

VHR data flow within the GSFC NCCS ADAPT HEC



Data Discovery- Automated Database

- Querying from a firefox browser on ADAPT:
  - Spatial search on individual image services.
  - Preview returned images; filter on attributes.
  - Create selection, and export to CSV or shapefile.
  - Query results can be sent to the API.



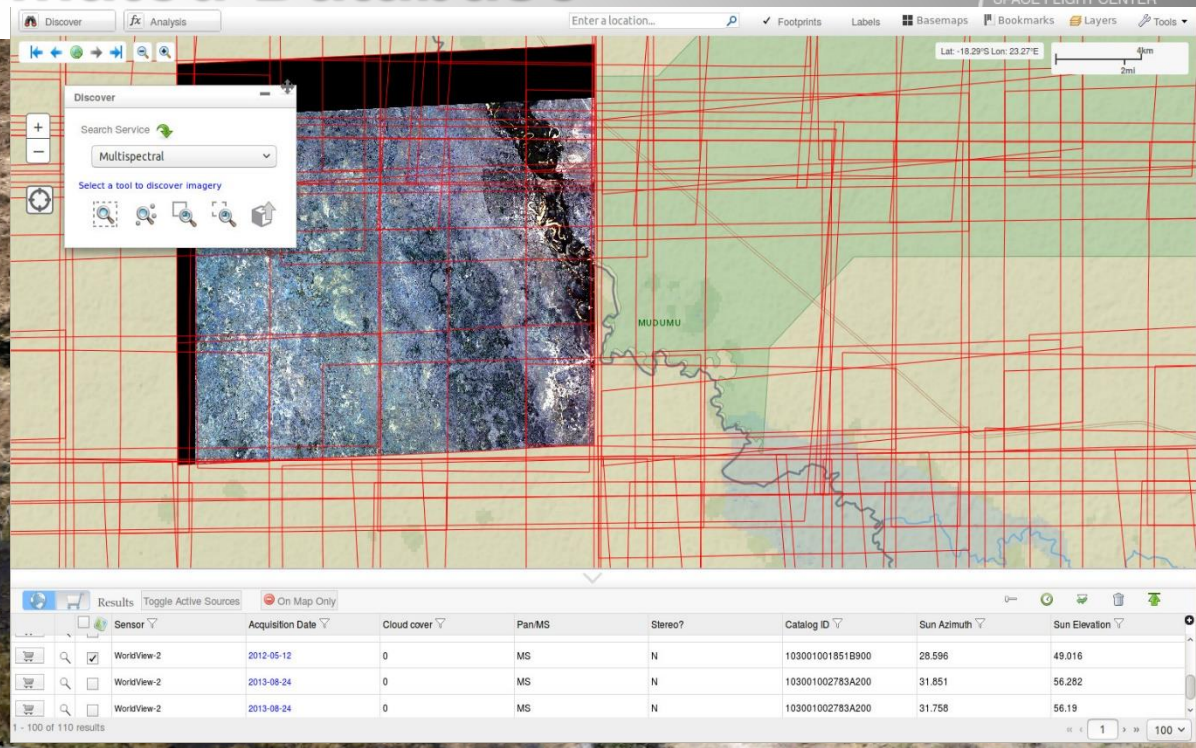
Data Discovery- Automated Database

Querying from a firefox browser on ADAPT:

- Spatial search on individual image services
- Preview returned images; filter on attributes
- Create selection, and export to CSV or shapefile
- Query results can be sent to the API

Recent Advances/Updates:

- Added capability to insert search parameters up-front to the query, to reduce returned results to a more manageable set of interest (eg via sensor, years/months, cloud-cover, etc.).
- Updated mosaic datasets with new imagery, and update image services.
- Created parallel mosaic datasets containing the reduced-resolution copies of the DG imagery, and integrated the resulting image services into the web query tool.



Okavango Delta, Botswana 7/07/19, *Validation of Landsat land cover mapping, NASA/CI Partnership, Air photo by C.S.R. Neigh*

EVHR Image Discovery Web Application

Usage Workflow Demo

https://cad4nasa-dev.gsfc.nasa.gov/ID-NGA

DEM Workflow: cont.
linking scientists with developers

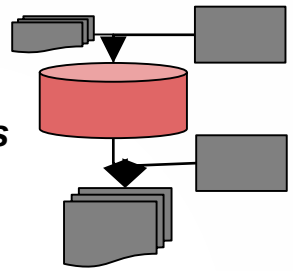
Optimize the workflow on the NCCS **ADAPT** linux cluster **(Collaborator Dan Duffy)**

- facilitate on-demand processing of imagery for study sites
- increase processing speed & efficiency, maximizing the use of HEC

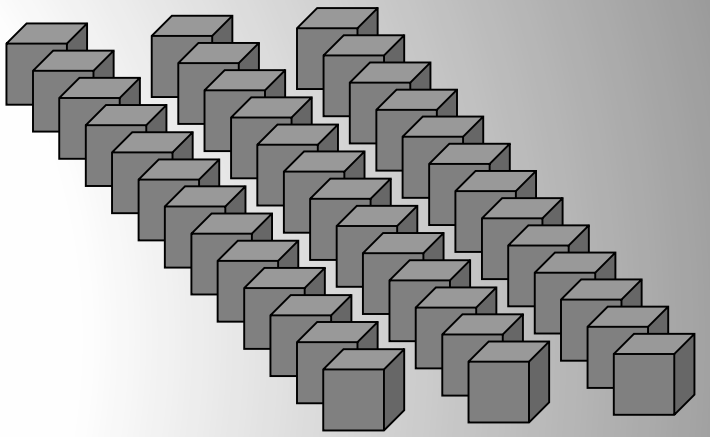
The workflow will benefit from interaction between scientists & developers

- To guide on-going software updates
- To inform software functionality based on science objectives.

DEM workflow



***ADAPT** linux cluster*

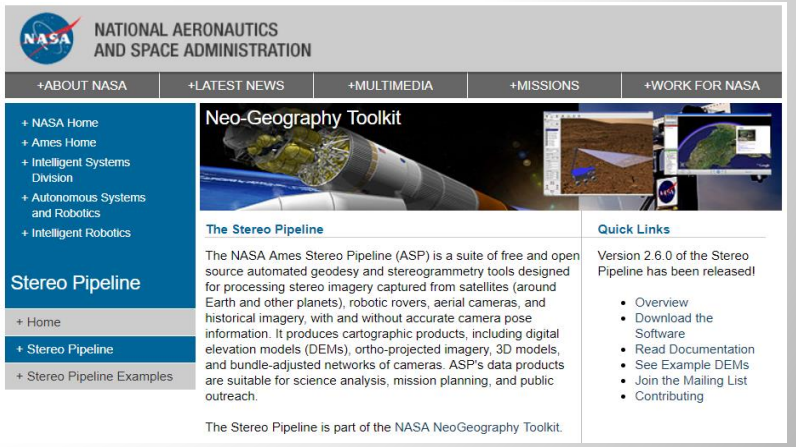


The NASA Ames Stereo Pipeline (**Co-I Oleg Alexandrov**)

- stereogrammetry routines for processing DigitalGlobe image pairs

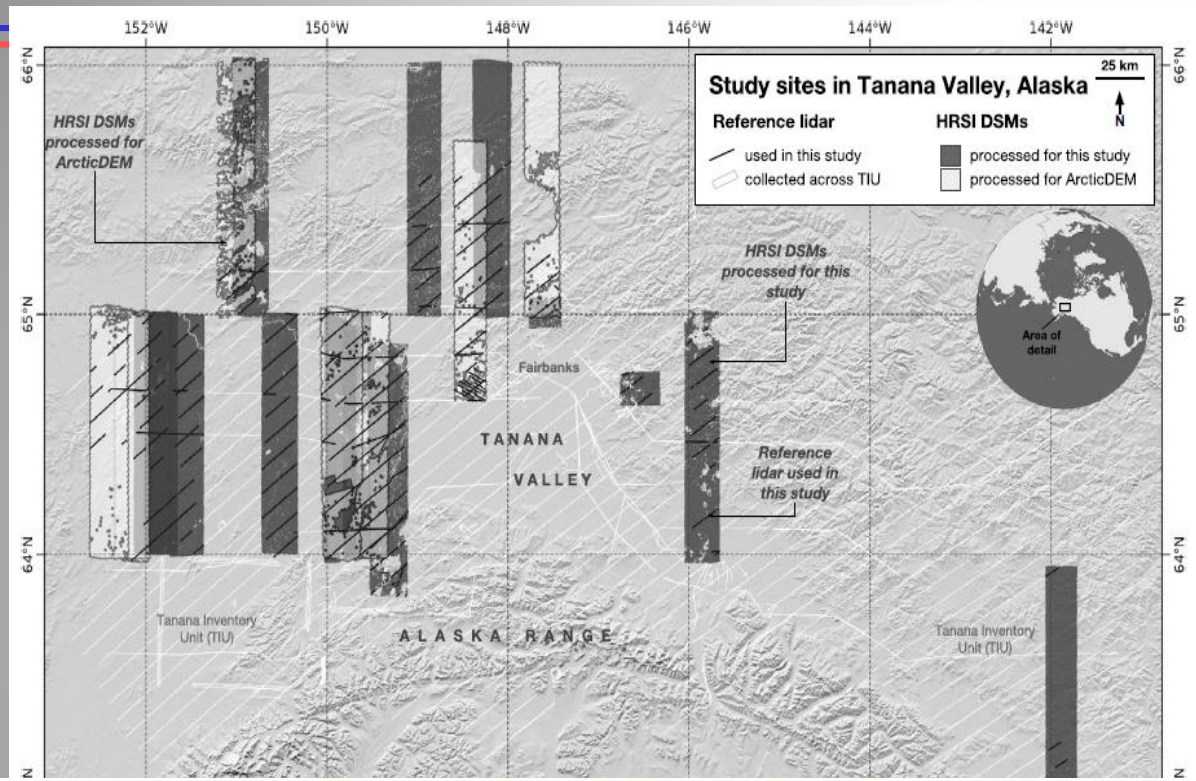
Python & bash scripts (**Co-I David Shean**)

- wrapper scripts to optimize the stereogrammetry workflow

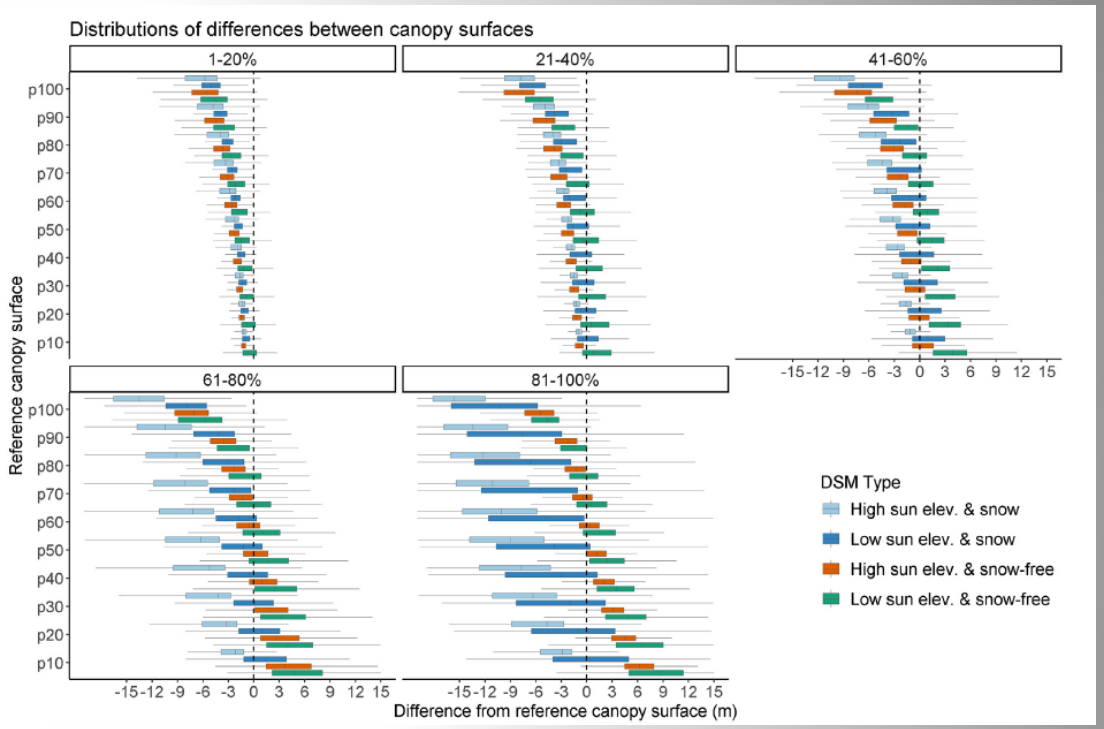


Shean, Alexandrov et al. P&RS 2016

HRSI DSM Vegetation Products Evaluated With GLiHT



Study sites in the Tanana Valley, Alaska where GLiHT lidar provided reference measurements of horizontal and vertical forest structure for coincident strips of DSMs (Upper). Aerial images highlight the diversity of forest structure patterns between sites (Lower).



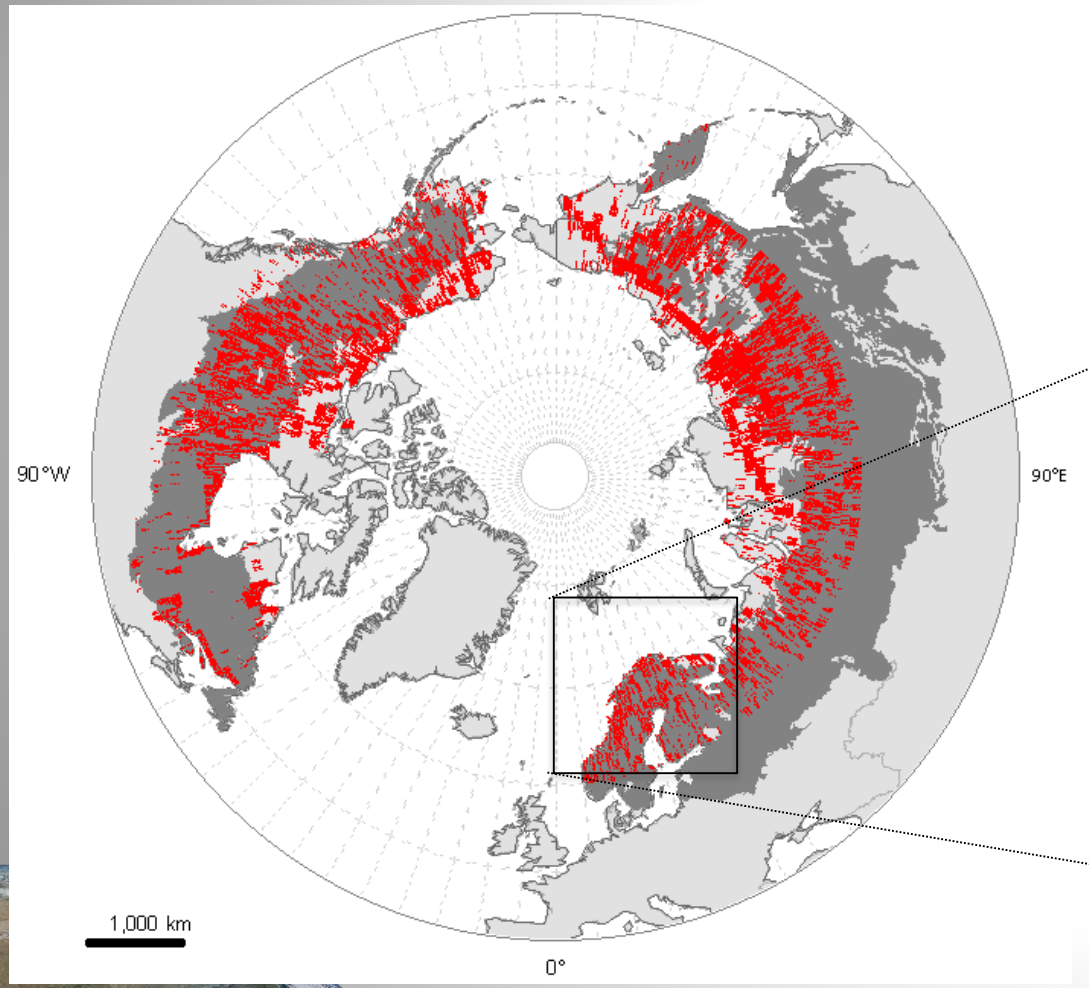
Boxplots show the distributions of differences between DSMs and reference canopy surfaces (GLiHT) for each DSM type across the 5 canopy cover intervals.

Montesano, Neigh et al. RSE 2019

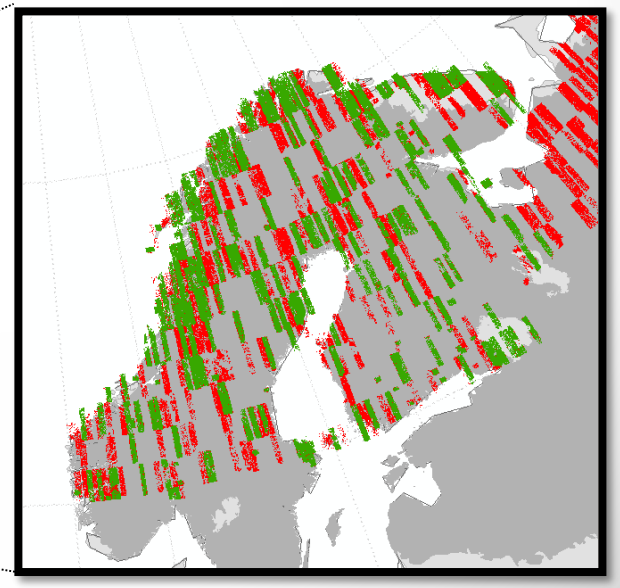
DEM Workflow: Scaled-up, API-adapted, Enhanced

Co-I Paul Montesano

Scaled-up: the results (> 7000 strips of DEMs) of HEC processing of the DEM Workflow across a global-scale vegetation domain (the circumpolar boreal forest)



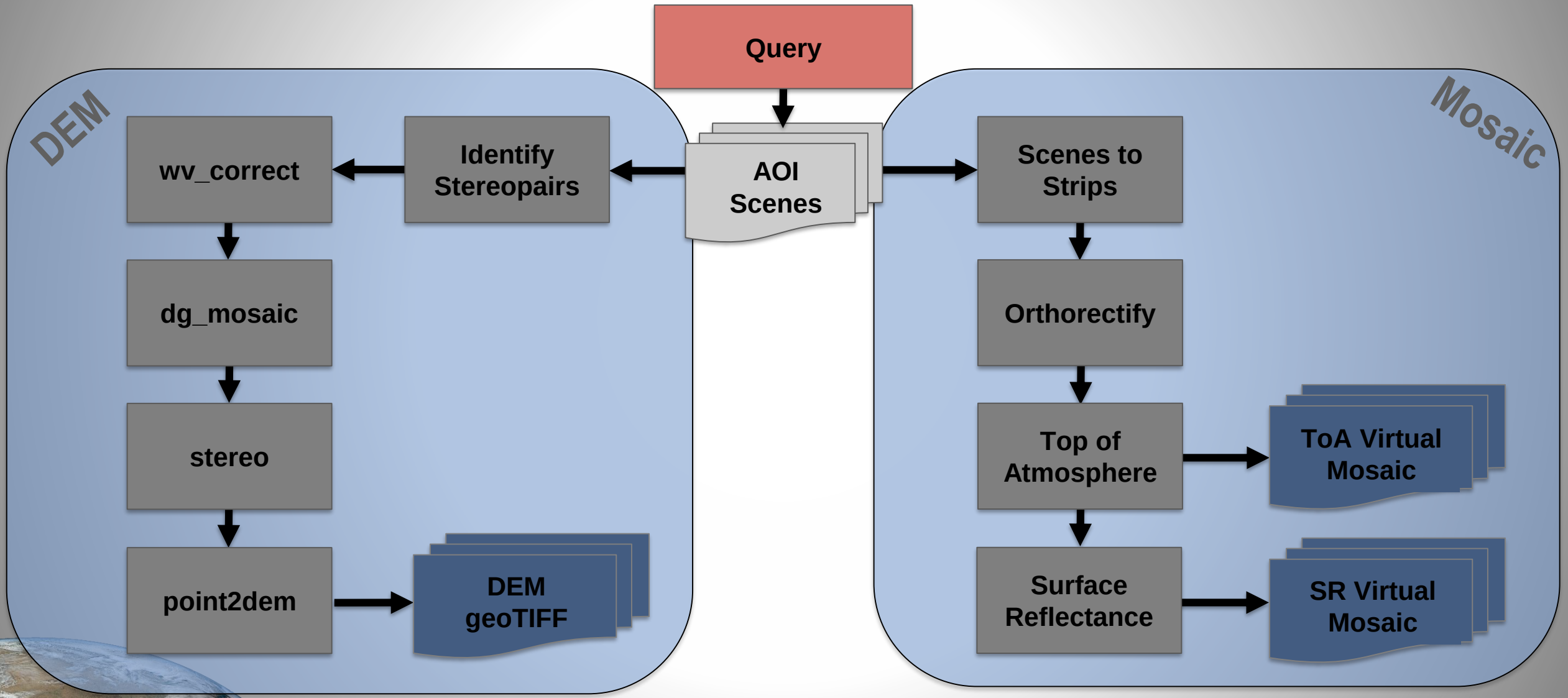
API-adapted: adapting the DEM Workflow to run routinely and flexibly (small scenes, large strips, single nodes, many nodes) on cluster VMs.



Standard: version of the DEM Workflow with ***Normalized Cross Correlation – NCC***.

Enhanced: version of the DEM Workflow with ***Semi Global Matching – SGM***.

Processing Workflow



Example API outputs

- **TOA Ortho**:

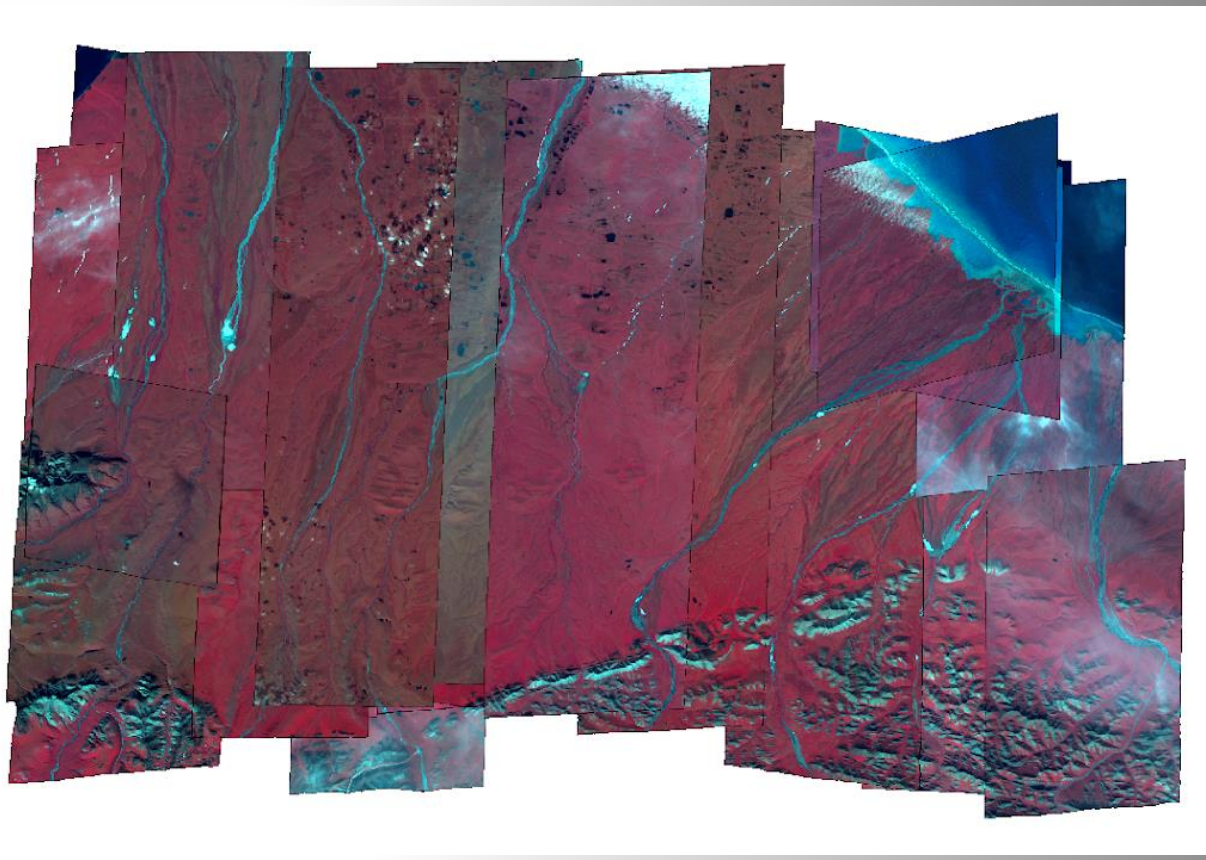
WV3 5/7/2015 RGB

Example API Outputs

- **DEM**: WV3 5/7/2015 RGB drapped on a WV2 stereo image 2/26/2012

Example API - Virtual Mosaic Outputs

- Top of Atmosphere and Surface Reflectance outputs will be delivered via Virtual Mosaics (.vrt)
  - Virtual Mosaics offers more flexibility and user control than a single output geoTIFF
  - User given both the virtual raster and underlying ToA and SR images
  - Can be converted into single-band raster image using proprietary or open-source software



29 strips July/Aug Eastern ANWR coastal plain

Technical Development Overview

We have found through our own research that VHR data provide a wealth of site level information that enhances NASA Earth observation products and scientific results.

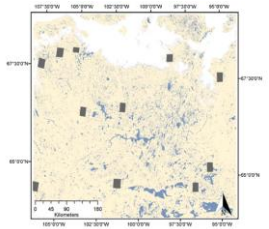
Our work builds on the significant progress from previous work supported by NASA's Programs:

- Terrestrial Ecology (TE)
- Carbon Cycle Science (CCS)
- Interdisciplinary Science (IDS)
- Cryospheric Sciences (CS)
- Advancing Collaborative Connections for Earth System Science (ACCESS)
- Land-Cover Land-Use (LCLUC)

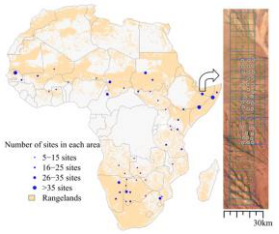
Numerous science applications can be performed with science ready VHR products!

Additional Projects/Data Use for Science

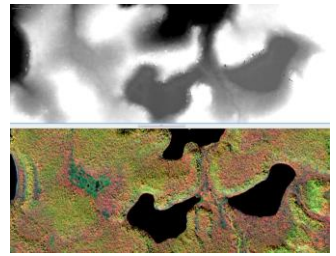
Surface water dynamics in North American Tundra – PI Carroll (TE - ABoVE)
Carroll and Laboda 2017 RS



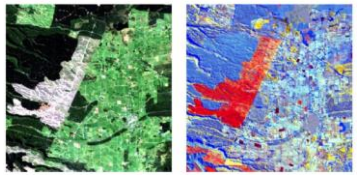
Analysis of woody vegetation properties and change across African savannas – PI Hanan (TE) *Axelsson et al. 2018 JB*



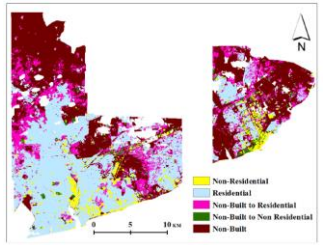
Validation of Landsat Tree Canopy Cover – PI Ranson (CCS)
Montesano et al. 2016 RS



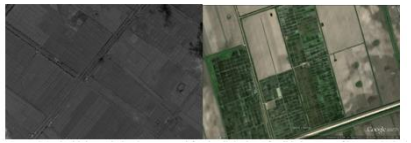
Disturbance analysis in New Zealand, mapping validation – PI (LCLUC)
de Beurs et al. 2016 IJAEOG



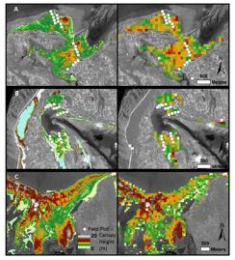
Improved fine scale urban change mapping – PI Stow (LCLUC)
Toure et al. 2018 RSE



Validation of paddy rice planting expansion in NE China– PI Dong (LCLUC)
Dong et al. 2015 RSE

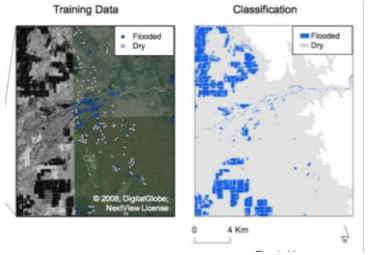


Mangrove canopy height estimation for blue carbon – PI Fatoyinbo (TE – CMS)
Lagomasino et al. 2016 RS

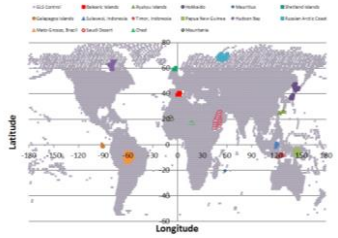


Changes in tall shrub abundance on the North Slope of Alaska – PI Chopping (TE- ABoVE)
Duchesne et al. 2018 RSE

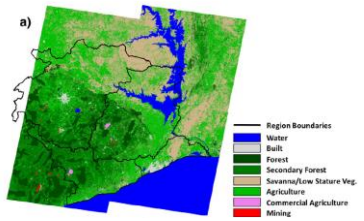
Training data for habitat mapping for shorebirds in California– PI Swenson (NESSF)
Schaffer-Smith et al. 2017 RSE



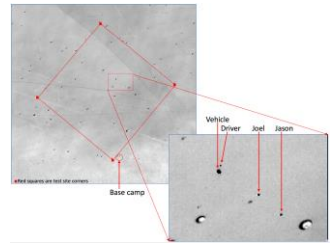
Landsat 8 Ground Control Point (GCP) improvements with WorldView – PI Storey (Landsat Science Team)



LCLUC in southern Ghana, validation – PI Stow (LCLUC)
Coulter et al. 2016 RSE



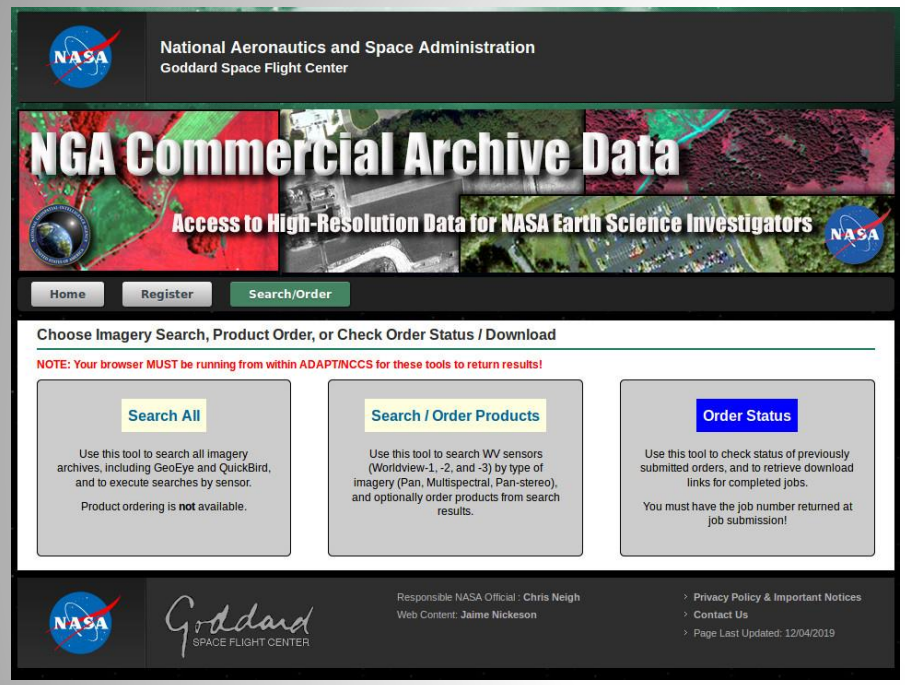
Characterizing a Cal/Val site in Bolivia – PI McCorkel (Landsat Science Team)



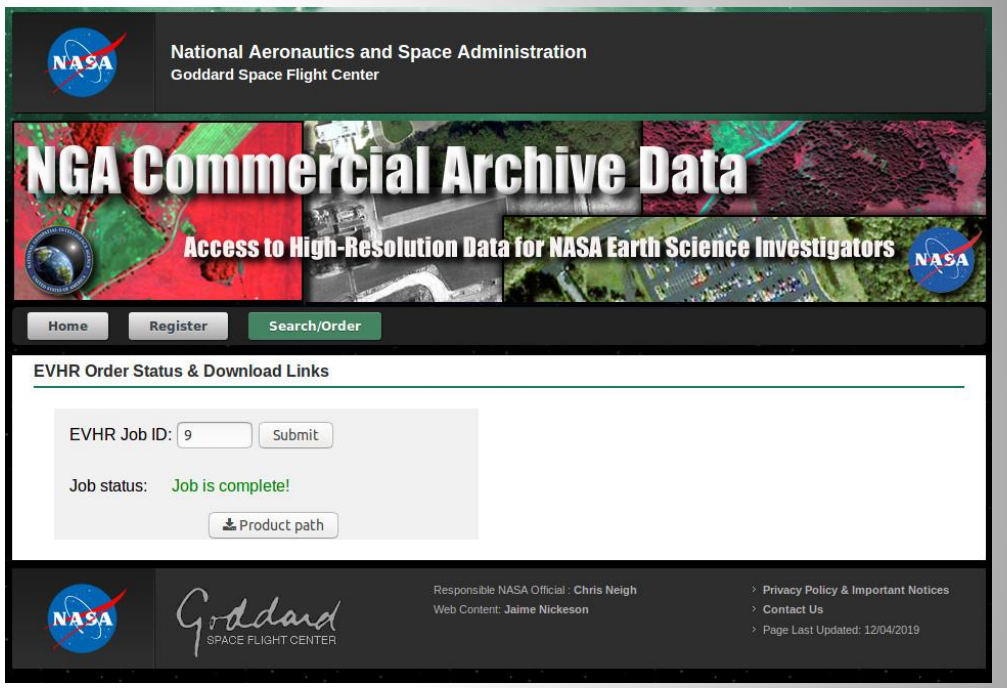
End-user Access Improvements

Co-I Dan Slayback

Image Discovery & EVHR Product Order Page



Order Status Page

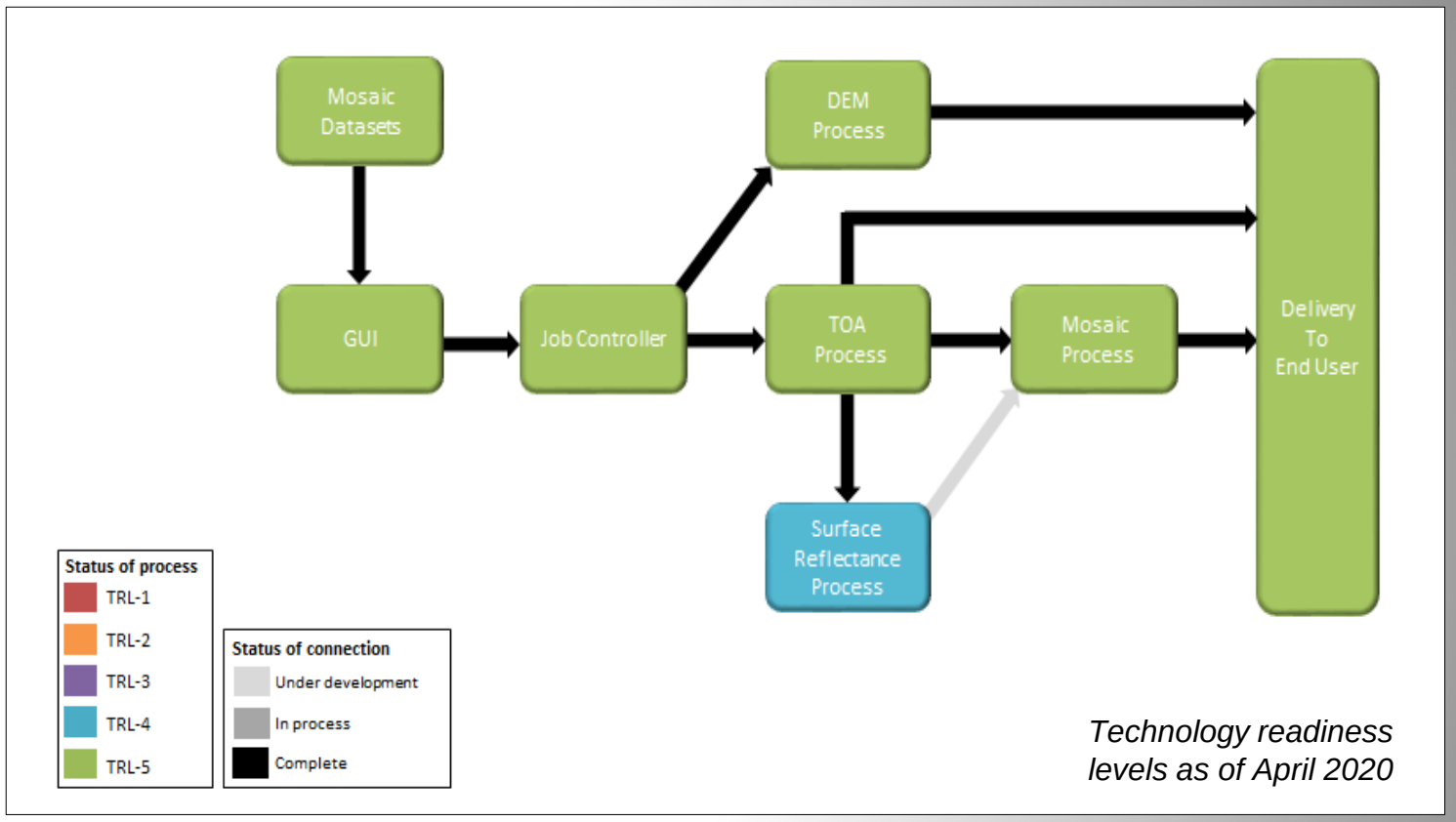


Plan for upgrades:

1. Update CAD4NASA website to include a single landing page Image Discovery/product ordering, and status querying:
    - Search All – launches the Image Discovery (ID) application referencing all holdings (including QuickBird, GeoEye, Ikonos), by sensor, but with no product ordering capabilities.
    - Search/Order – launches the ID application with EVHR-capable datasets (Worldview-1,2,3), with product ordering capabilities enabled.
    - Order Status – links to a new order status page, allowing user to check status of previously submitted jobs, and retrieve path to completed product files.
2. Updated mosaic datasets with new imagery, and implemented back-end upgrades.

Summary

- Processed >TB of Top of Atmosphere and DEM outputs through API
- The API mosaic processer has run end-to-end producing 1,000's of ortho'ed TOA images.



Technology readiness levels as of April 2020

https://cad4nasa-dev.gsfc.nasa.gov/ID-NGA

Thank You

Axelsson, C.R., & Hanan, N.P. (2018). Rates of woody encroachment in African savannas reflect water constraints and fire disturbance. *Journal of Biogeography*, 1-10.

Coulter, L.L., Stow, D.A., Tsai, Y.H., Ibanez, N., Shih, H.C., Kerr, A., Benza, M., Weeks, J.R., & Mensah, F. (2016). Classification and assessment of land cover and land use change in southern Ghana using dense stacks of Landsat 7 ETM + imagery. Remote Sensing of Environment, 184, 396-409.

de Beurs, K.M., Owsley, B.C., & Julian, J.P. (2016). Disturbance analyses of forests and grasslands with MODIS and Landsat in New Zealand. International Journal of Applied Earth Observation and Geoinformation, 45, 42-54.

Dong, J.W., Xiao, X.M., Kou, W.L., Qin, Y.W., Zhang, G.L., Li, L., Jin, C., Zhou, Y.T., Wang, J., Biradar, C., Liu, J.Y., & Moore, B. (2015). Tracking the dynamics of paddy rice planting area in 1986-2010 through time series Landsat images and phenology-based algorithms. Remote Sensing of Environment, 160, 99-113.

Dronova, I., Gong, P., Wang, L., & Zhong, L.H. (2015). Mapping dynamic cover types in a large seasonally flooded wetland using extended principal component analysis and object-based classification. Remote Sensing of Environment, 158, 193-206.

Frost, G.V., Epstein, H.E., & Walker, D.A. (2014). Regional and landscape-scale variability of Landsat-observed vegetation dynamics in northwest Siberian tundra. Environmental Research Letters, 9.

Jain, M., Mondal, P., DeFries, R.S., Small, C., & Galford, G.L. (2013). Mapping cropping intensity of smallholder farms: A comparison of methods using multiple sensors. Remote Sensing of Environment, 134, 210-223.

Lagomasino, D., Fatoyinbo, T., Lee, S., Feliciano, E., Trettin, C., & Simard, M. (2016). A Comparison of Mangrove Canopy Height Using Multiple Independent Measurements from Land, Air, and Space. Remote Sensing, 8.

Neigh C.S.R., Masek J., and Nickeson J. (2013) High Resolution Satellite Data Open to Government Scientists. AGU EOS Transactions 94 (13), 121-123. 10.1002/2013EO130002

Neigh, C., Masek, J., Bourget, P., Cook, B., Huang, C., Rishmawi, K., & Zhao, F. (2014). Deciphering the Precision of Stereo IKONOS Canopy Height Models for US Forests with G-LiHT Airborne LiDAR. *Remote Sensing, 6*, 1762-1782. 10.3390/rs6031762

Neigh, C.S.R., McCorkel, J., & Middleton, E.M. (2015). Quantifying Libya-4 Surface Reflectance Heterogeneity With WorldView-1, 2 and EO-1 Hyperion. IEEE Geoscience and Remote Sensing Letters, 12, 2277-2281. 10.1109/LGRS.2015.2468174

Neigh, C.S.R., McCorkel, J., Campbell, P.K.E., Ong, L., Ly, V., Landis, D., & Middleton, E.M. (2016). Monitoring Orbital Precession of EO-1 Hyperion With Three Atmospheric Correction Models in the Libya-4 PICS. *Ieee Geoscience and Remote Sensing Letters, 13*, 1797-1801. 10.1109/lgrs.2016.2612539

Neigh, C.S.R., Masek, J.G., Bourget, P., Rishmawi, K., Zhou, F., Huang, C., Cook, B., & Nelson, R.F. (2016). Regional rates of young US forest growth estimated from annual Landsat disturbance history and IKONOS stereo imagery. Remote Sensing of Environment, 173, 282-293. 10.1016/j.rse.2015.09.007

Neigh, C.S.R., Carroll, M., Wooten, M.R., Powell, B., McCarty, J.L., Husak, G.J., Enenkel, M., & Hain, C. (2018). Smallholder crop area mapped with wall-to-wall WorldView sub-meter panchromatic image texture: a test case for Tigray, Ethiopia. Remote Sensing of Environment, 212, 8-20. 10.1016/j.rse.2018.04.025

McCarty, J.L., Neigh, C.S.R., Carroll, M.L., & Wooten, M.R. (2017). Extracting smallholder cropped area in Tigray, Ethiopia with wall-to-wall sub-meter WorldView and moderate resolution Landsat 8 imagery. Remote Sensing of Environment, 202, 142-15. 10.1016/j.rse.2017.06.040

Montesano P.M., Neigh C.S.R., Sexton J., Feng M., Channan S., Ranson K.J., and Townshend J.R. (2016) Calibration and Validation of Landsat Tree Cover in the Taiga−Tundra Ecotone. *Remote Sensing* , *8,* 551. 10.3390/rs8070551

Montesano, P., Neigh, C.S.R., Sun, G., Duncanson, L.I., Van Den Hoek, J., & Ranson, J. (2017). The use of sun elevation angle for stereogrammetric boreal forest height in open canopies. *Remote Sensing of Environment, 196*, 76-88. 10.1016/j.rse.2017.04.024

Montesano, P., Neigh, C.S.R., Wagner, W., Wooten, M., & Cook, B.D. (2019). Boreal canopy surfaces from spaceborne stereogrammetry. Remote Sensing of Environment, 225, 148-159. 10.1016/j.rse.2019.02.012

Schaffer-Smith, D., Swenson, J.J., Barbaree, B., & Reiter, M.E. (2017). Three decades of Landsat-derived spring surface water dynamics in an agricultural wetland mosaic; Implications for migratory shorebirds. Remote Sensing of Environment, 193, 180-192.

Shean, D.E., Alexandrov, O., Moratto, Z., Smith, B., Joughin, I.R., Porter, C., & Morin, P. (2016). An automated, open-source pipeline for mass production of digital elevation models (DEMs) from very-high-resolution commercial stereo satellite imagery. *ISPRS Journal of Photogrammetry and Remote Sensing, 116* 101-11.