How to Cloud for Earth Scientists:
The ABoVE Science Cloud on ADAPT

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NASA Carbon Cycle and Ecosystems Office
Contributors

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- Garrison Vaughn, System Architect and Applications Engineer
- Ellen Salmon, Computer Research and Development
- Laura Carriere, System Analyst
- Julien Peters, Software Developer
- Others.....
ABoVE is a large-scale study of environmental change in Arctic and boreal regions and the implications for ecological systems and society

Overarching Science Question:

How vulnerable or resilient are ecosystems and society to environmental change in the Arctic and boreal region of western North America?
Vulnerability - Resilience Framework

Causes of Change

Social Systems

Changes to Ecosystems

Ecosystem Services
Where are we working?

- 80 total projects (including NASA funded, Partner, Affiliated)

- 550 participants from universities, national agencies/labs, state/provincial/territorial groups, private, and native/aboriginal organizations

- Summer airborne campaign:
  - 10 aircraft, 20 deployments, and 200 science flights
  - April to October 2017
  - 4 million km² in Alaska and Canada
Why do we need a new approach?

• Science datasets are becoming larger, with intensive computation needed for data processing

• And collaboration across diverse research groups is essential,

• But it is often time consuming and expensive to transfer, download, process and share data with others

• Therefore the ABoVE Science Cloud (ASC) was created to meet the needs of ABoVE investigators and encourage collaboration within the field campaign.
Integrated high-end computing environment supporting the specialized requirements of Climate and Weather modeling.

- High-performance computing, data storage, and networking technologies
- High-speed access to petabytes of Earth Science data
- Collaborative data sharing and publication services
- Advanced Data Analytics Platform (ADAPT)

Primary Customers (NASA Climate Science)

- Global Modeling and Assimilation Office (GMAO)
- Goddard Institute for Space Studies (GISS)

High-Performance Science

- [http://www.nccs.nasa.gov](http://www.nccs.nasa.gov)
- Located in Building 28 at Goddard
- Dan Duffy, High Performance Computing Lead (Code 606.2)
## Analysis is Different than HPC

<table>
<thead>
<tr>
<th>High Performance Computing</th>
<th>Data Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Takes in small amounts of input and creates large amounts of output</em>...</td>
<td><em>Takes in large amounts of input and creates a small amount of output</em>...</td>
</tr>
<tr>
<td>Relatively small amount of observation data, models generate forecasts</td>
<td>Large amounts of observational/model data generate science</td>
</tr>
<tr>
<td>Tightly coupled processes require synchronization within the simulation</td>
<td>Loosely coupled processes requiring little to no synchronization</td>
</tr>
<tr>
<td>Simulation applications are typically 100,000’s of lines of code</td>
<td>Analysis applications are typically 100’s of lines of code</td>
</tr>
<tr>
<td>Fortran, Message Passing Interface (MPI), large shared parallel file systems</td>
<td>Python, IDL, Matlab, custom</td>
</tr>
<tr>
<td>Rigid environment – users adhere to the HPC systems</td>
<td>Agile environment – users run in their own environments</td>
</tr>
</tbody>
</table>
Advanced Data Analytics Platform (ADAPT)  
“High Performance Science Cloud”

High Performance Science Cloud is uniquely positioned to provide data processing and analytic services for NASA Science projects. A portion of ADAPT is dedicated to ABoVE (the ABoVE Science Cloud).

Adjunct to the NCCS HPC environment
- Lower barrier to entry for scientists
- Customized run-time environments
- Reusable HPC/Discover hardware

Expanded customer base
- Scientist brings their analysis to the data
- Extensible storage; build and expand as needed
- Persistent data services build in virtual machines
- Create purpose built VMs for specific science projects

Difference between a commodity cloud
- Platform-as-a-Service
- Critical Node-to-node communication – high speed, low latency
- Shared, high performance file system
- Management and rapid provisioning of resources
The ABoVE Science Cloud is the center of the data lifecycle.

Augmented from Rüegg et al 2014 in Front Ecol Environ

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The ABoVE Science Cloud is the center of the data lifecycle.

Augmented from Rüegg et al 2014 in *Front Ecol Environ*
### System Components/Configuration

<table>
<thead>
<tr>
<th>Capability and Description</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Persistent Data Services</strong></td>
<td>Nodes with 128 GB of RAM, 10 GbE, and FDR IB</td>
</tr>
<tr>
<td>Virtual machines or containers deployed for web services, examples include ESGF, GDS, THREDDS, FTP, etc.</td>
<td></td>
</tr>
<tr>
<td><strong>DataBase</strong></td>
<td>Nodes with 128 GB of RAM, 3.2 TB of SSD, 10 GbE, and FDR IB</td>
</tr>
<tr>
<td>High available database nodes with solid state disk.</td>
<td></td>
</tr>
<tr>
<td><strong>Remote Visualization - planned</strong></td>
<td>Nodes with 128 GB of RAM, 10 GbE, FDR IB, and GPUs</td>
</tr>
<tr>
<td>Enable server side graphical processing and rendering of data.</td>
<td></td>
</tr>
<tr>
<td><strong>High Performance Compute</strong></td>
<td>~100 nodes with between 24 and 64 GB of RAM and FDR IB</td>
</tr>
<tr>
<td>More than 1,000 cores coupled via high speed Infiniband networks for elastic or itinerant computing requirements.</td>
<td></td>
</tr>
<tr>
<td><strong>High-Speed/High-Capacity Storage</strong></td>
<td>Storage nodes configured with multiple PB’s of RAW storage capacity</td>
</tr>
<tr>
<td>Petabytes of storage accessible to all the above capabilities over the high speed Infiniband network.</td>
<td></td>
</tr>
</tbody>
</table>
ASC Software Stack

- **External License Servers**: Virtual machines can be set up to reach out to external license servers.
- **Open Source Tools**: Python, NetCDF, etc.
- **Commercial Tools**: Intel Compiler (C, C++, Fortran), IDL (4 seats)
- **Operating Systems**: Linux (Debian, CentOS) and Windows

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Staged / Common Data Sets in ABoVE Science Cloud

Common datasets “Staged” for ABoVE investigators in ABoVE Science Cloud

• Staged and available for direct use
• Individual investigators don’t have to invest time to locate and transfer data into system
• Avoids duplications of large datasets on system
• Additional datasets can be added, including generated data from ABoVE PI
• Data Services Manager to locate data

Example Download Times For 80TB

<table>
<thead>
<tr>
<th>Speed</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.6 Kbps</td>
<td>18518s</td>
</tr>
<tr>
<td>14.4 Kbps</td>
<td>12346s</td>
</tr>
<tr>
<td>28.8 Kbps</td>
<td>6178s</td>
</tr>
<tr>
<td>33.6 Kbps</td>
<td>5291s</td>
</tr>
<tr>
<td>56 Kbps</td>
<td>3174s</td>
</tr>
<tr>
<td>64 Kbps (ISDN)</td>
<td>2777s</td>
</tr>
<tr>
<td>128 Kbps (ISDN-2)</td>
<td>1388s</td>
</tr>
<tr>
<td>256 Kbps</td>
<td>5914s</td>
</tr>
<tr>
<td>512 Kbps</td>
<td>3472s</td>
</tr>
<tr>
<td>1.024 Mbps</td>
<td>1736s</td>
</tr>
<tr>
<td>1.544 Mbps (DS1, T1)</td>
<td>1135s</td>
</tr>
<tr>
<td>2.048 Mbps (E1, ISDN-32)</td>
<td>8680s</td>
</tr>
<tr>
<td>10 Mbps (10Base-T)</td>
<td>1777s</td>
</tr>
<tr>
<td>25.6 Mbps (ATM25)</td>
<td>5914s</td>
</tr>
<tr>
<td>34 Mbps (E3)</td>
<td>3220s</td>
</tr>
<tr>
<td>45 Mbps (DS3, T3)</td>
<td>3500s</td>
</tr>
<tr>
<td>61 Mbps (OC1)</td>
<td>3485s</td>
</tr>
<tr>
<td>100 Mbps (100Base-T)</td>
<td>1777s</td>
</tr>
<tr>
<td>165 Mbps (OC3)</td>
<td>1146s</td>
</tr>
<tr>
<td>622 Mbps (OC12)</td>
<td>285s</td>
</tr>
<tr>
<td>1 Gbps (1000Base-T)</td>
<td>1777s</td>
</tr>
<tr>
<td>2.4 Gbps (OC48)</td>
<td>74s</td>
</tr>
<tr>
<td>10 Gbps (OC192)</td>
<td>17s</td>
</tr>
</tbody>
</table>

7.4 Mbps average US internet speed
1 Gbps NASA / Other Gov

@10 Mbps
Days: 741
Weeks: 106
Months: 24

@1 Gbps
Days: 7
Weeks: 1.1
Months: 0.25
### ABoVE Science Cloud Data Holdings

<table>
<thead>
<tr>
<th>Large Collections</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat</td>
<td>186 TB</td>
</tr>
<tr>
<td>MODIS</td>
<td>MODAPS collection remotely mounted</td>
</tr>
<tr>
<td>MERRA &amp; MERRA2</td>
<td>406 TB</td>
</tr>
<tr>
<td>DigitalGlobe Imagery</td>
<td>2.8 PB</td>
</tr>
<tr>
<td>Total</td>
<td>&gt; 3 PB</td>
</tr>
</tbody>
</table>

### Other Data Sets

- Elevation datasets: ArcticDEM, CDEM, ASTER GDEM, etc.
- Vegetation products
- Land cover products
- Products generated by the science team

*Others as the team requests...

Find a list of all common datasets available on the ASC here &gt;>
NGA/DigitalGlobe High Resolution Commercial Satellite Imagery

National Geospatial Intelligence Agency (NGA) has licensed all DigitalGlobe ≥ 31 cm satellite imagery for US Federal use, i.e., NSF, NASA and NASA funded projects.

- Archive of >4.2 billion km² of data from 2000 to present
- Data from six different satellites: Worldview-1, 2 and 3; Ikonos; Quickbird; and Geoeye-1

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Bands</th>
<th>Nadir Panchromatic Resolution (m)</th>
<th>Nadir Multispectral Resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ikonos</td>
<td>Pan, R, G, B, Near IR</td>
<td>0.82</td>
<td>3.2</td>
</tr>
<tr>
<td>GeoEye</td>
<td>Pan, R, G, B, Near IR</td>
<td>0.41</td>
<td>1.65</td>
</tr>
<tr>
<td>Quickbird</td>
<td>Pan, R, G, B, Near IR</td>
<td>0.55</td>
<td>2.16</td>
</tr>
<tr>
<td>WorldView-1</td>
<td>Panchromatic only</td>
<td>0.5</td>
<td>N/A</td>
</tr>
<tr>
<td>WorldView-2</td>
<td>Pan, R, G, B, Near IR 1, Near IR 2, Coastal, Red Edge, Yellow</td>
<td>0.46</td>
<td>1.85</td>
</tr>
<tr>
<td>WorldView-3</td>
<td>Same as WV-2 plus 8 SWIR bands and 12 CAVIS bands</td>
<td>0.31</td>
<td>1.24</td>
</tr>
</tbody>
</table>
ABoVE Science Cloud DigitalGlobe Imagery: Study Domain
ABoVE Science Cloud DigitalGlobe Imagery: Circumpolar
Examples of the ASC In Action
• Fire history across the ABoVE study region is compiled from available and new (Miller et al. in prep) data products and enhanced

• Multiple VMs on the ASC are used to process Landsat and MODIS data to develop the burn severity characterization
Forest Canopy Surface Elevations – C. Neigh & P. Montesano

- Understanding forest patterns using DigitalGlobe high-resolution satellite imagery

- Using multiple VMs and Ames Stereo Pipeline (ASP) on the ASC to process Digital Elevation Models
Landscape-Scale Histories of Disturbance, Seasonality and Greenness Trends - C. Woodcock & D. Sulla-Menashe

• 30+ year historical record and ongoing characterization of disturbance events and phenology across the ABoVE study domain

• Using multiple VMs to move Landsat data into the ABoVE grid and then develop the landscape histories
Understanding the Causes and Implications of Enhanced Seasonal CO₂ Exchange in Boreal and Arctic Ecosystems – B. Rogers

- Modeling driving factors of post-fire albedo trajectories
- Creation of mean albedo maps
- Fire combustion mapping
The ABoVE Science Cloud (ASC)

Referenced on page A 4-8 in NASA Research Announcement for Terrestrial Ecology: Airborne Campaign For ABoVE

Science Cloud Setup Instructions
About the Science Cloud
Webinar

The NASA Center for Climate Simulation (NCCS) has partnered with the NASA Carbon Cycle and Ecosystems Office (CCE Office) to create a high performance science cloud for this field campaign. The ABoVE Science Cloud combines high performance computing with emerging technologies and data management tools for analyzing and processing geographic information to create an environment specifically designed for large-scale modeling, analysis of remote sensing data, copious disk storage for “big data” with integrated data management, and integration of core variables from in-situ networks. The ABoVE Science Cloud is a collaboration that promises to accelerate the pace of new Arctic science for researchers participating in the field campaign. Furthermore, by
Seeing the ABoVE Science Cloud in Action
Presentation by Mark Carroll
Transitioning from workstation to cloud computing

Mark Carroll
Biospheric Sciences Lab
Science Systems and Applications Inc.
Determining the Extent and Dynamics of Surface Water for the ABoVE Field Campaign

• Utilize the dense time series of Landsat data in the North American Arctic to create a time series of surface water maps
• We use the full available time series to minimize the impact of anomalous weather events (drought, flood) in individual scenes
• These maps can be used to identify hotspots of change and to identify field sites for study during the ABoVE campaign
Determining the Extent and Dynamics of Surface Water for the ABoVE Field Campaign

- Decision tree classification on each Landsat scene
- Extract theme (water) from each date, build data stack
- Sum water observations for entire epoch
- Mosaic each themed scene into ABoVE tile (no overlap)
- Sum mosaicked tiles to create a total per theme for each ABoVE tile (utilizes all available observations including overlap)
Determining the Extent and Dynamics of Surface Water for the ABoVE Field Campaign

- Original processing plan involved a couple of workstations and rotating data through an 8TB RAID
- Anticipated processing time 9 – 12 months
- Only final outputs would be kept online
- No time available for reprocessing
- Enter the Science Cloud at NCCS and GSFC High Performance Computing
Determining the Extent and Dynamics of Surface Water for the ABoVE Field Campaign

• Final result is a time series of three maps 10 years apart that can be used to show not only the location of water at a given time period but also the change in surface water extent through time.
Regional annual water

- Northern Nunavut province in Canada
- Includes Queen Maud Gulf Bird Sanctuary
- Limited impact from anthropogenic pressures
Regional annual water
## Regional annual water

<table>
<thead>
<tr>
<th>size in ha</th>
<th>&lt;0.1</th>
<th>0.1 to 1</th>
<th>1 to 10</th>
<th>10 to 100</th>
<th>100 to 1,000</th>
<th>1,000 to 10,000</th>
<th>10,000 to 100,000</th>
<th>&gt;100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>total</td>
<td>251,884</td>
<td>202,412</td>
<td>167,450</td>
<td>48,495</td>
<td>4,836</td>
<td>257</td>
<td>29</td>
<td>9</td>
</tr>
<tr>
<td>change p0.05</td>
<td>52,475</td>
<td>55,081</td>
<td>45,724</td>
<td>13,330</td>
<td>1,369</td>
<td>62</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>fraction(total)</td>
<td>21%</td>
<td>27%</td>
<td>27%</td>
<td>27%</td>
<td>28%</td>
<td>24%</td>
<td>14%</td>
<td>22%</td>
</tr>
<tr>
<td>decreasing</td>
<td>31,810</td>
<td>21,438</td>
<td>17,216</td>
<td>4,960</td>
<td>527</td>
<td>32</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>increasing</td>
<td>20,665</td>
<td>33,643</td>
<td>28,508</td>
<td>8,370</td>
<td>842</td>
<td>30</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>d fraction</td>
<td>61%</td>
<td>39%</td>
<td>38%</td>
<td>37%</td>
<td>38%</td>
<td>52%</td>
<td>75%</td>
<td>100%</td>
</tr>
<tr>
<td>l fraction</td>
<td>39%</td>
<td>61%</td>
<td>62%</td>
<td>63%</td>
<td>62%</td>
<td>48%</td>
<td>25%</td>
<td>0%</td>
</tr>
</tbody>
</table>

- Over 60% of water bodies are < 1 ha
- Smallest and largest water bodies decreasing in size
- Middle sized water bodies are increasing
Regional annual water

- Over 675,000 water bodies in the study area
- Linear regression (OLS) performed on area per water body per year
- Over 168,000 water bodies exhibit change with $p < 0.05$
Crop Mapping Tigray, Ethiopia

Tigray crop mapping

- Initial plan was to use very high resolution data to train a classification algorithm
- Given data and processing capability in the cloud we transitioned to using VHR to generate the entire map
- Methodology began in linear fashion treating scenes individually
- Experience showed that generating mosaics prior to classification improved results
- Along the way a new approach to evaluation was created
Crop Mapping Tigray, Ethiopia

Method Evolution

- Image on left shows original method using VHR data that resulted in distinct boundaries between scenes
- Image on right shows the improved method with far fewer errors and hard boundaries between scenes
- Working in the cloud enabled rapid reprocessing and assembly of thousands of scenes in just a few days
  - There are ~85 billion pixels in the mosaicked maps
  - Nearly 500 billion pixels were processed to get enough information to generate these mosaics
  - End to end processing can be completed in just a few days
Standardize the processing of the image pairs returned from data discovery:

• with tested parameters

• incorporate lessons learned from 3000+ DEMs processed using 6000+ image strip pairs
Reduce high start-up costs associated with working with massive datasets on HEC platforms

Extend science opportunities to other PIs

Our automated DEM workflow will streamline the (1) ingest & (2) processing of stereopairs, and (3) output of science-ready DEMs and orthoimages.

Example of a science product derived from an analysis of DSMs processed with a preliminary workflow. Vegetation height in an open-canopy boreal forest of western Siberian.

Montesano, Neigh et al. RSE 2017
Automated protocols for generating very high-resolution commercial validation products with NASA HEC resources

PI: Chris Neigh, NASA GSFC

Goals and Objectives
Enhance scientific utility of sub-meter DigitalGlobe data by:

1) Improving VHR data discovery: using databases and mosaic datasets within NASA-GSFC’s ADAPT global archive of DG VHR imagery;

2) Producing on demand VHR 1/2° degree mosaics: automating estimates of surface reflectance, ortho-rectifying and normalized 1 m mosaics for pan and 2 m for multi-spectral; and

3) Producing on demand 2 m posting DEMs: leveraging HEC processing and open source NASA-ARC ASP software.

Architecture Overview

Approach
Develop a HEC API to:
1. identify NASA-GSFC archived VHR DG data and Ortho-rectify, atmospherically correct, identify clouds/shadows, mosaic, and convert to GeoTiff in a standard GIS ready projection;
2. identify NASA-GSFC archived VHR DG stereo pair data and produce orthos and DEMs.

Co-Is/Collaborators
Mr. Mark Carroll, Dr. Paul Montesano, Dr. Compton Tucker, Dr. Alexei Lyapustin, Dr. Daniel Slayback, Dr. David Shean, Dr. Oleg Alexandrov, Mr. Mathew Macander, Dr. Daniel Duffy, Dr. Jorge Pinzon, Dr. Gerald Frost and Dr. Scott Goetz

Key Milestones

Automated database, beta 07/2018 TRL_{in} = 2
Surface reflectance WV-2, beta 10/2018
½° Mosaics and DEMs, beta 1/2019
System Interface, API, beta 05/2019
Optimization of performance 07/2019
Client libraries and API tools completed 10/2019 TRL_{out} = 5
Conclusions

- Six years ago all of my work was accomplished on local workstations
- Since then I have transitioned nearly all of my workflows into the cloud to take advantage of distributed and parallel processing
- This has freed up time to do analysis and enabled me to ask bigger questions
- Future plans all focus on use of cloud technologies to facilitate the processing of large datasets to answer science questions