Department of the Interior
USGS – National Unmanned Aircraft Systems Project Office

uas.usgs.gov

Jeff Sloan
USGS-Geosciences & Environmental Change Science Center
National UAS Project Office
Denver, Colorado USA
August 2016

Outline

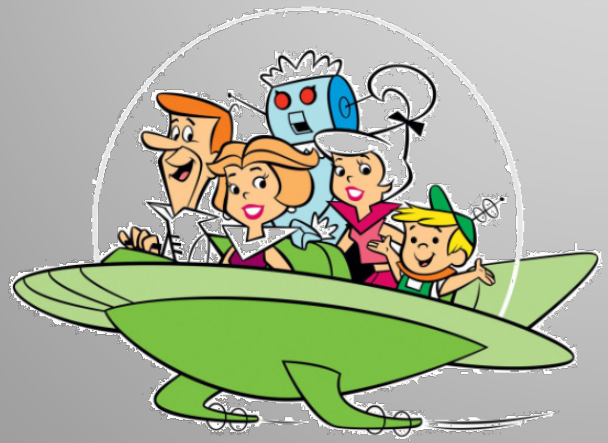
- Why is there so much interest in this technology?
- History – to better describe how UAS technology fits in with Dept. of the Interior work
- How to make it work
  - What are the rules to legally fly within the National Airspace?
  - Safety, cost savings, and better data?
  - Proof-of-concept missions over the past 5 years
- Goal: Just another tool in the toolbox for scientists?

Outline

- **Why is there so much interest in this technology?**

Cool Factor?

New Way of Life?



Privacy?


EYE IN THE SKY
MAN SHOOTS DOWN DRONE HOVERING OVER HOUSE


PREPARE FOR THE DRONE APOCALYPSE.
-THE INVASION OF PRIVACY!


caglecartoons.com
© HARTFORD COURANT
"I ALWAYS CARRY IT WITH ME NOW. IT'S A DRONE SWATTER!"

Wanting More Information
Different Ways of Looking at it?

Or… a very useful tool?

USGS
science for a changing world

Unmanned Aircraft Systems (UAS) Applications in the Department of the Interior

Wildlife Studies

Anaho Island National Wildlife Refuge, NV
Census of Ground-nesting Colonial Waterbirds


Grand County, CO
Monitoring Breeding Greater Sage-Grouse

Pygmy Rabbit Habitat Study, ID

Monte Vista National Wildlife Refuge, CO
Sand Hill Crane Population Estimates

Environmental Monitoring

White Sands National Monument, New Mexico
Survey & Document Paleontological Pleistocene Tracks

Haleakala National Park, Kula, Hawaii
Assess Park Boundary Fences and Detect Invasive Plants and Animals

Mojave National Preserve, CA
Identify Abandoned Materials

Central Platte River Valley, NE
Mapping Emergent Sandbar Habitats

Volumetric Studies

Contour Surface Coal Mines, WV
Inspecting Coal Mining Permits

Coal Basin Mine Project, CO
Inspect Abandoned Mine Lands (AML)

Hydrologic Monitoring

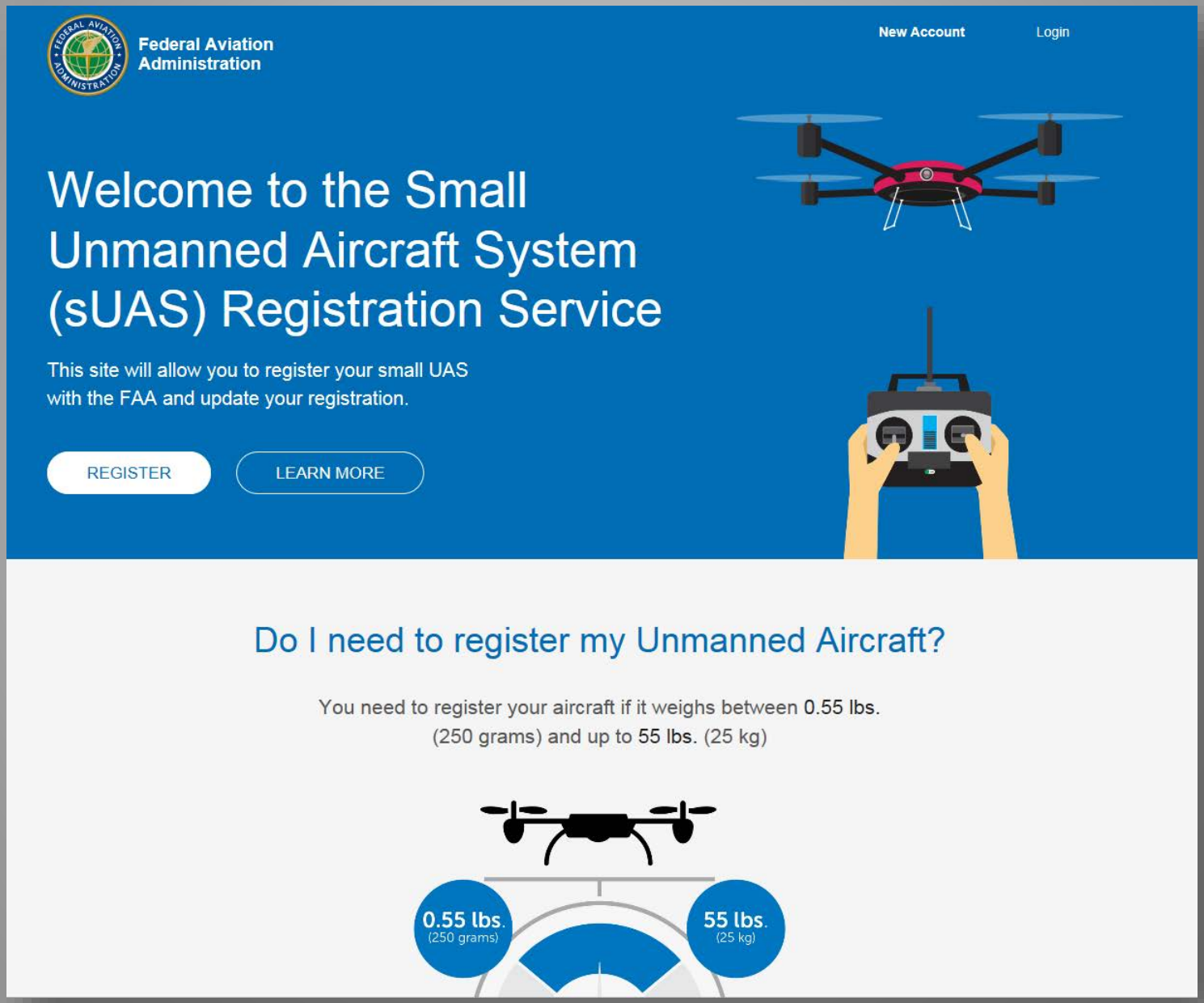
Red Rock Lakes National Wildlife Refuge, MT
Ground Water Discharge Monitoring

Missouri River, SD
Monitor Erosion of River Shoreline

For more information please contact
Bruce K. Quirk, Ph.D.
Land Remote Sensing Program - UAS Liaison
quirk@usgs.gov
(703) 648-5736

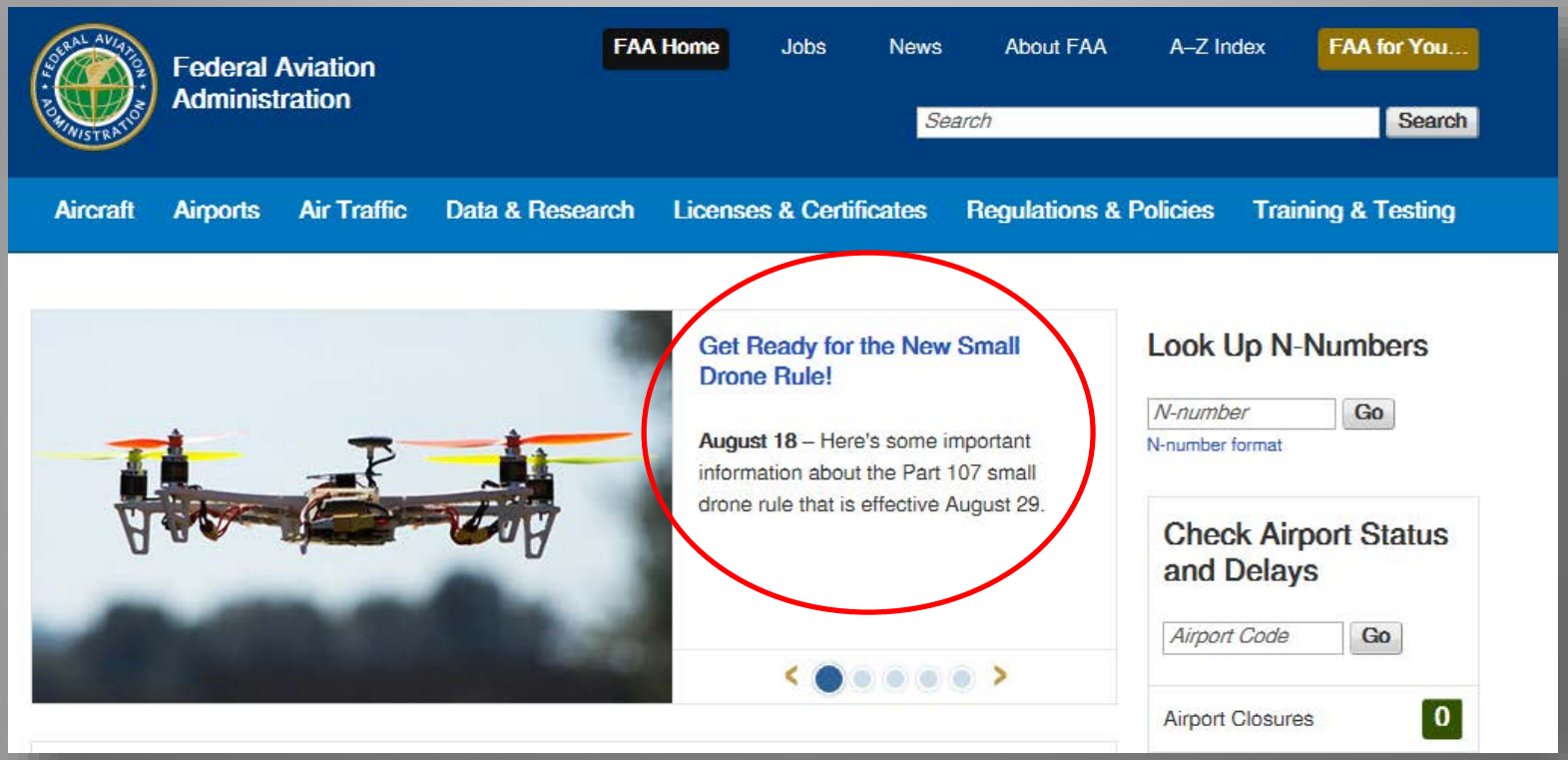
or visit our website
NATIONAL UNMANNED AIRCRAFT SYSTEMS PROJECT OFFICE
http://uas.usgs.gov

FAA Small UAS Registration



FAA Small UAS Registration

New Rules for Small UAS

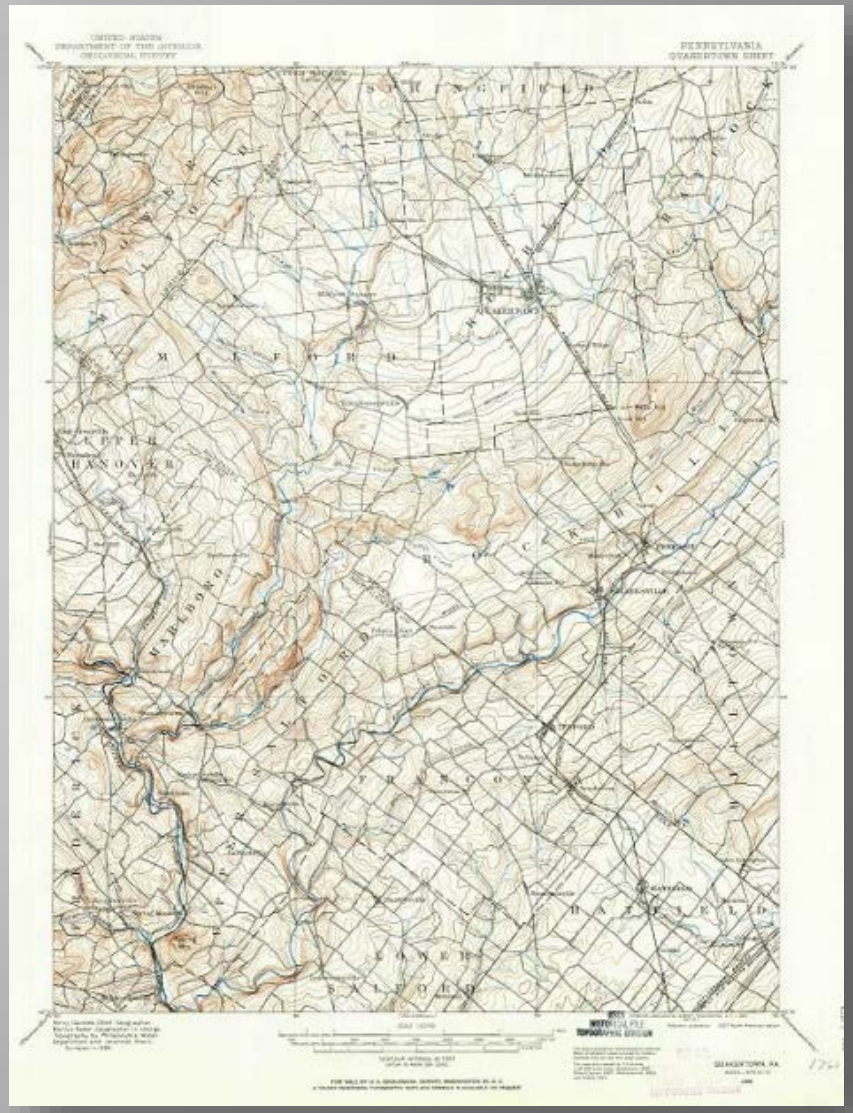


Outline

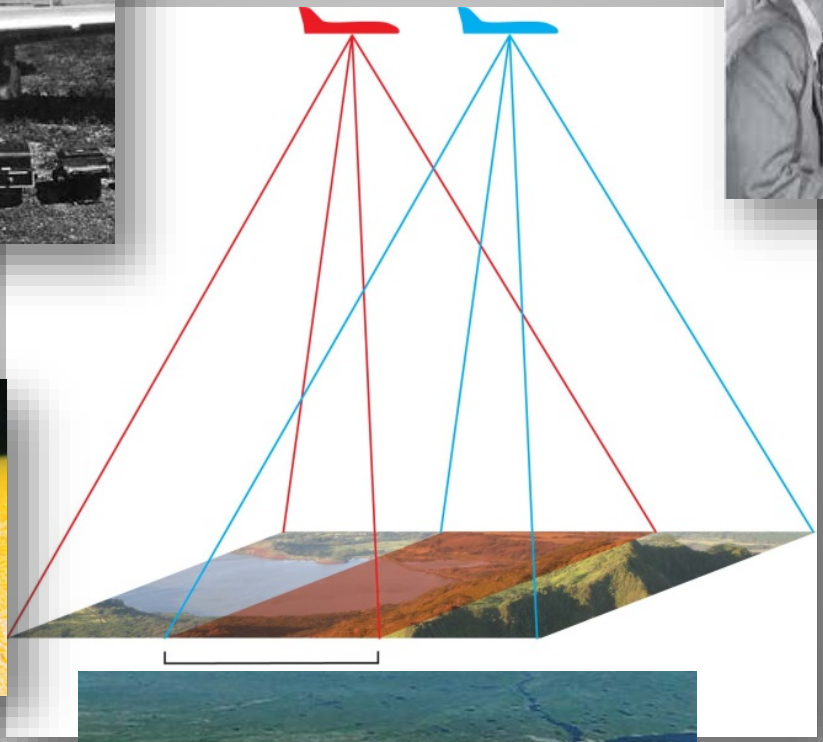
- **History – to better describe how UAS technology fits in with Dept. of the Interior work**

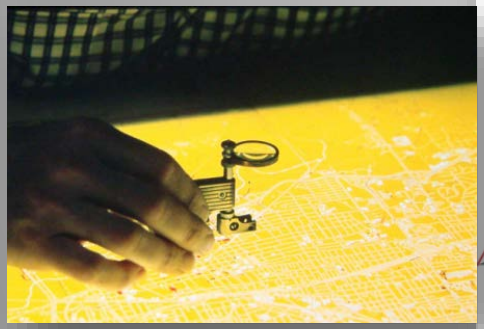
History

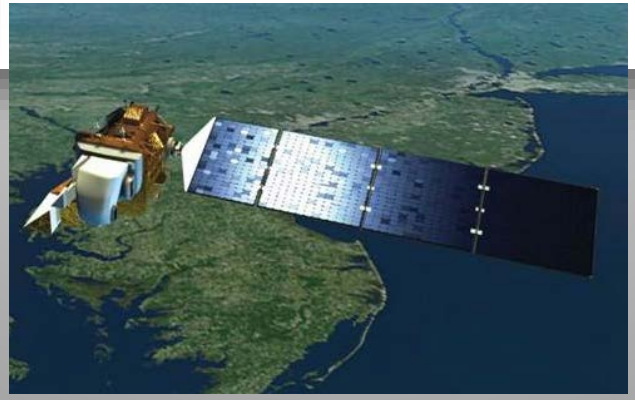

U.S. GEOLOGICAL SURVEY
ELEVATION
ABOVE SEA
FEET
DATUM
1915
B.M.



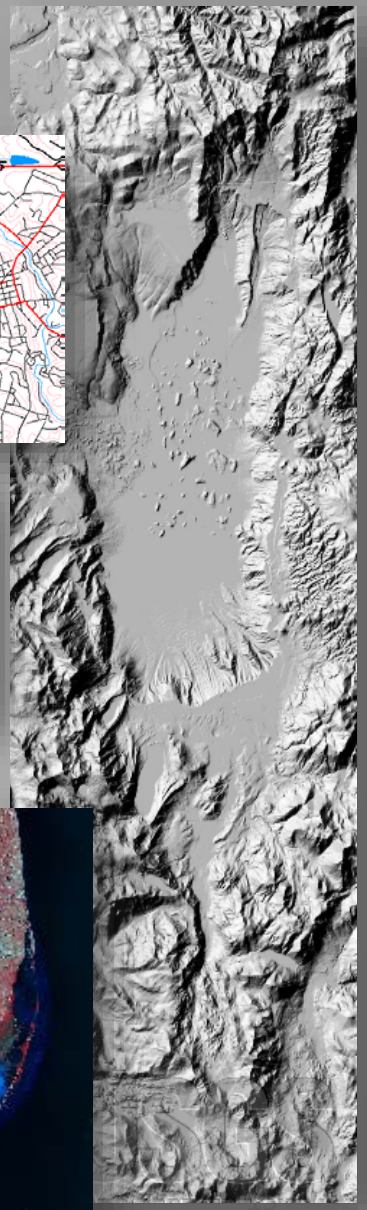
History

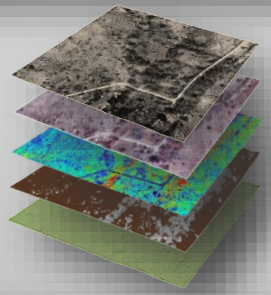




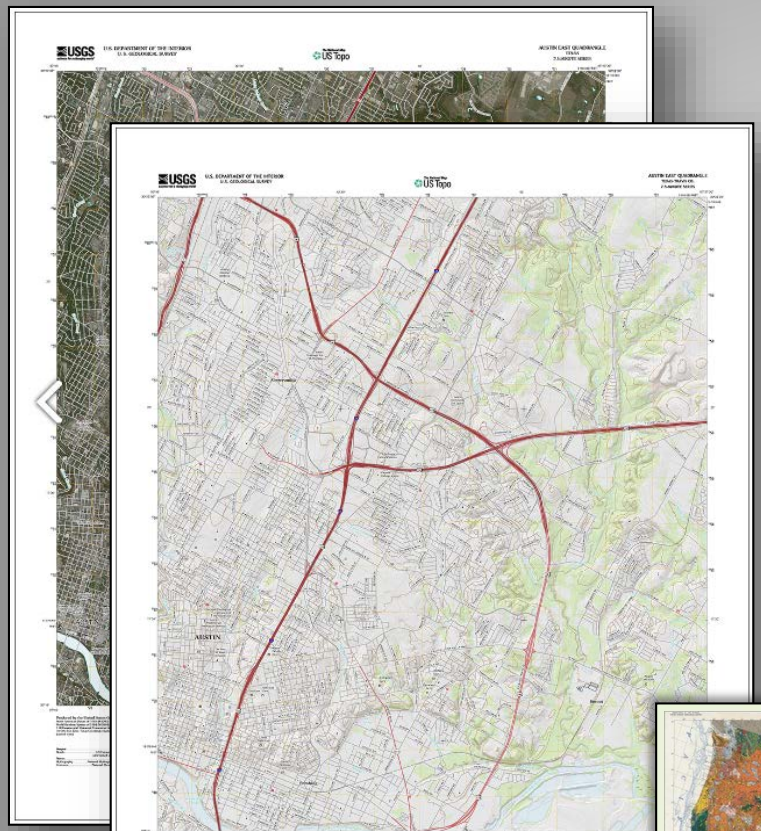


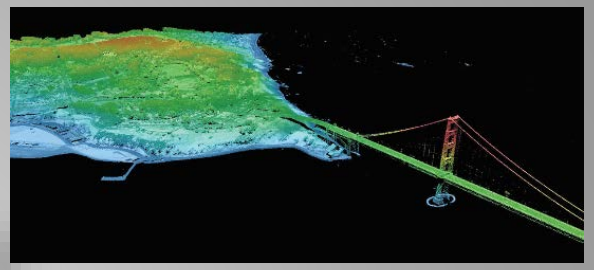
History

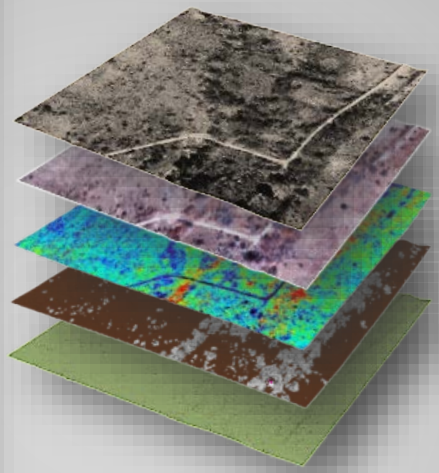


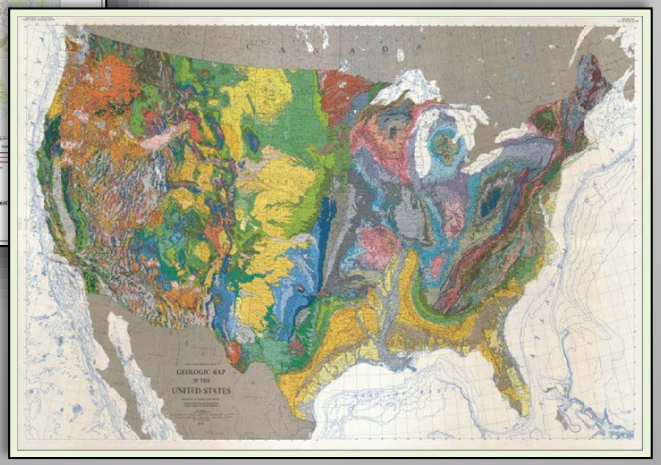


History



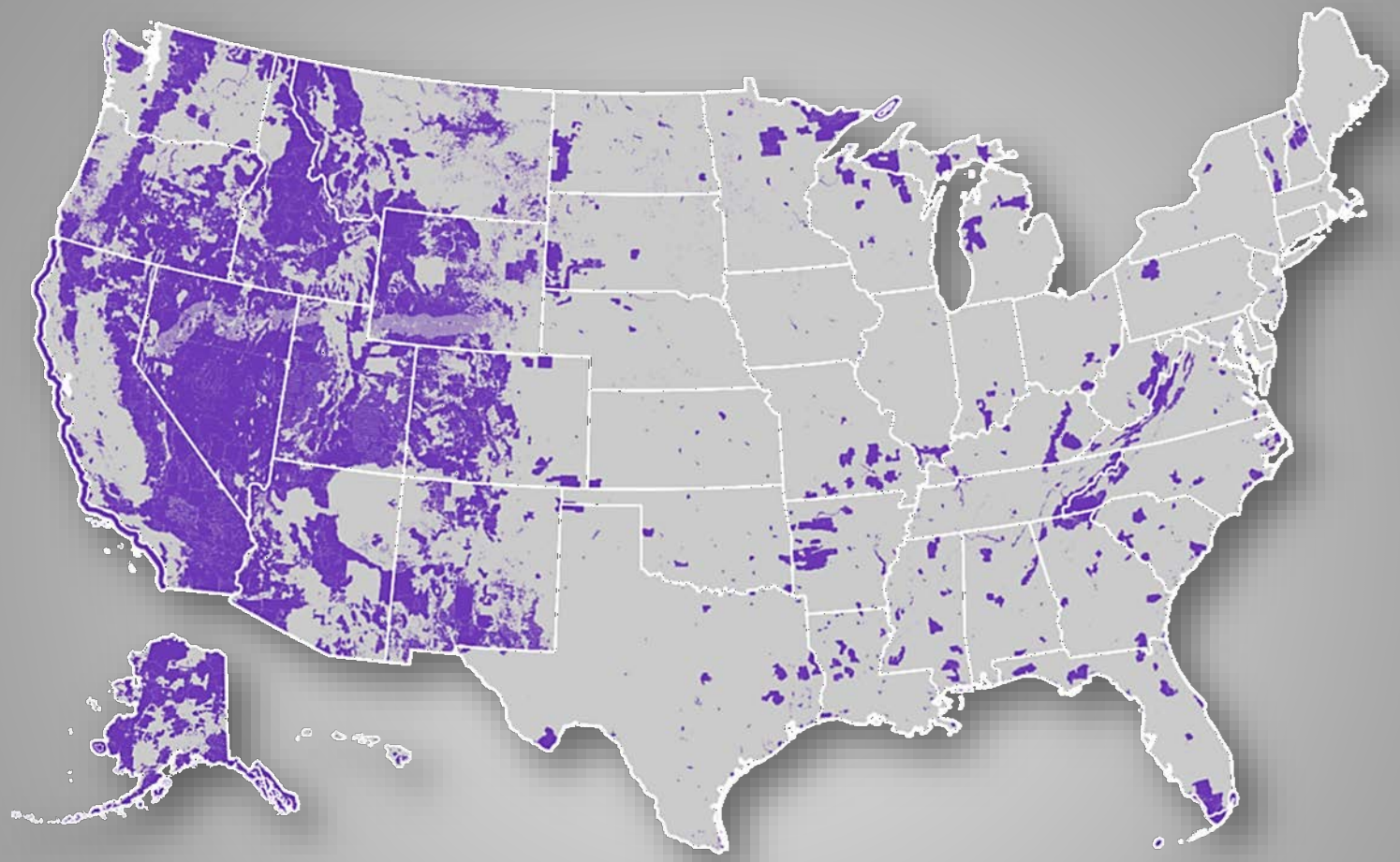






Department of the Interior

Federally Managed Lands



507 million acres of land - 1 out of every 5 acres in U.S.
is the Dept. of the Interior's management responsibility

**U.S. Geological Survey, Bureau of Land Management, Bureau of Indian Affairs,
Office of Surface Mining Reclamation and Enforcement,
Bureau of Reclamation, National Park Service, U.S. Fish & Wildlife Service**

USGS science for a changing world

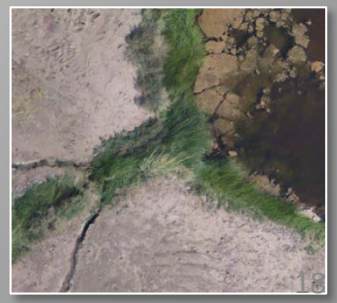
Sources of Remote Sensing Data

Low altitude role of small UAS in data acquisition

Landsat 8 (30 meter)

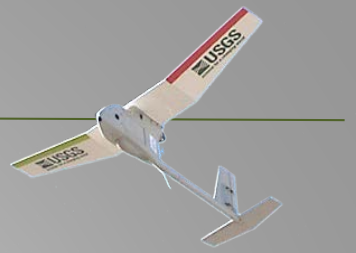
NAIP 2010 (1 meter)

UAS at 400 ft (5 cm)



UAS at 200 ft (2.5 cm)

USGS UAS History



- Emerging Technology Investigations……2004-2008
- USGS UAS National Project Office Created……May 2008
- First Systems (Raven) Acquired……Aug. 2009
- Operator Training……2009-2010
- Operations in the National Airspace……March 2011

Outline

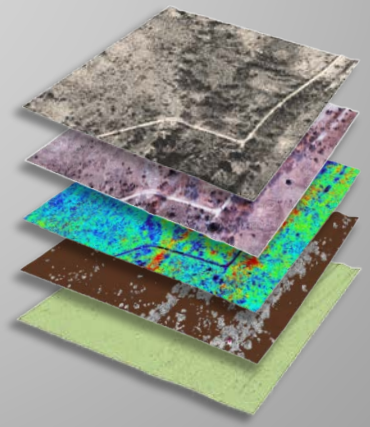
- **How to make it work**
  - What are the rules to legally fly within the National Airspace?
  - Safety, cost savings, and better data?
  - Proof-of-concept missions over the past 5 years

How to Make It All Work

- **Platform**

- **Sensor**

- **Data Processing**



Dept. of the Interior - UAS Platforms

2009-2015

AeroVironment – Raven RQ-11A

Honeywell - T-Hawk

MLB Super Bat

PRESENT

3DR Solo

Falcon Fixed Wing

Falcon Hover

Pulse Vapor 55

Sensors

Point & Shoot, MILC and DSLR Cameras

High Definition Video

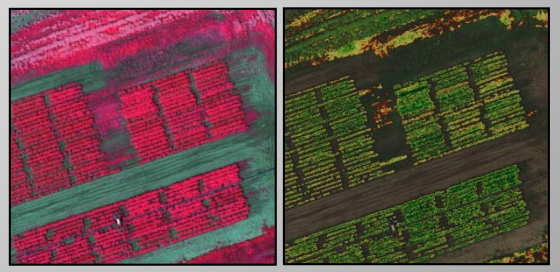
Thermal Sensor

FLIR

Courtesy of FLIR Tau 2 Sample Images

Multispectral Sensor

MicaSense



Courtesy of MicaSense Sample images

Future Sensors

- **Geomagnetometers**
- **Hyperspectral Sensors**
- **Natural Color High Resolution Medium Format**
- **Telemetry**
- **Radar**

LiDAR

Hyperspectral

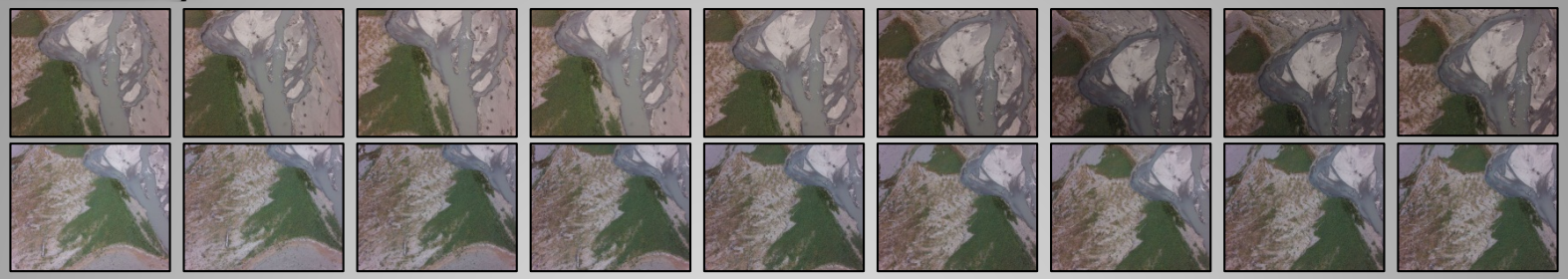
Magnetometers

Medium Format

Geospatial Product Creation

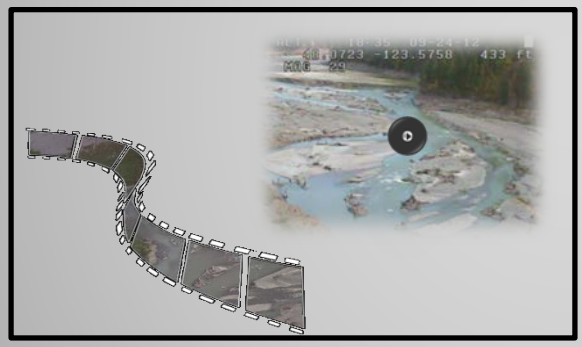
With Data Acquired from UAS

(Computer Vision - Structure-From-Motion)



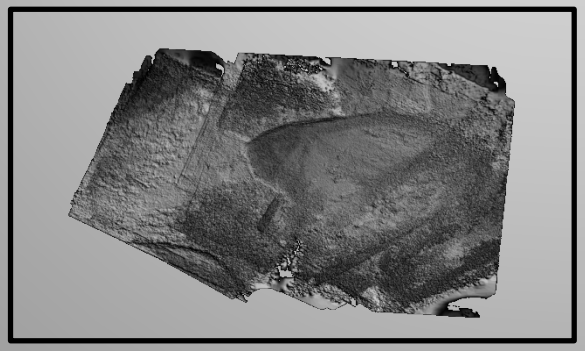
STILL FRAME IMAGES CAPTURED ON-BOARD THE UNMANNED AIRCRAFT

GoPro Hero2 – 11 megapixel (compressed)

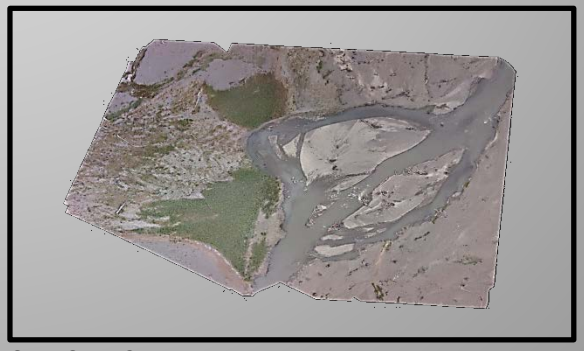


FULL-MOTION VIDEO

3-D POINT CLOUD DATA



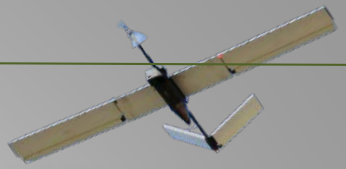
ELEVATION MODELS

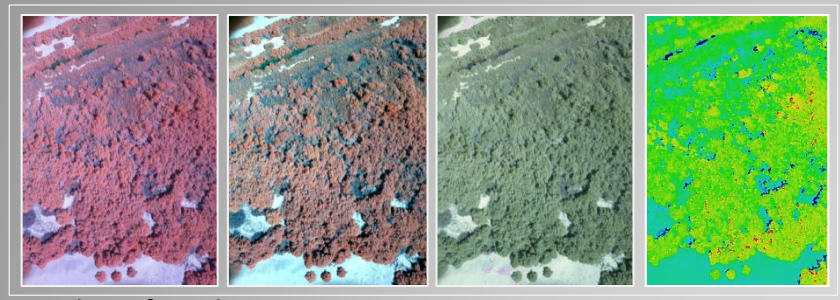


ORTHOIMAGERY

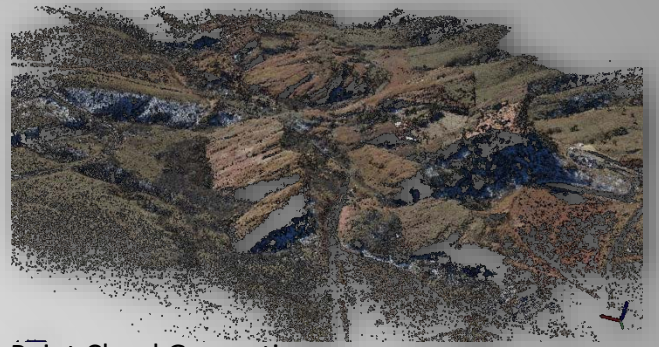
USGS science for a changing world

Derived Geospatial Products

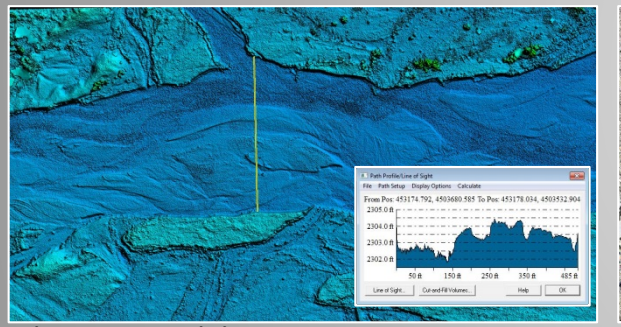




Color Infrared - NDVI

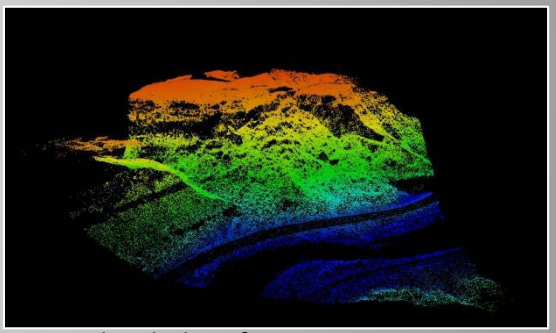


Point Cloud Generation



Elevation Models

Feature Extraction

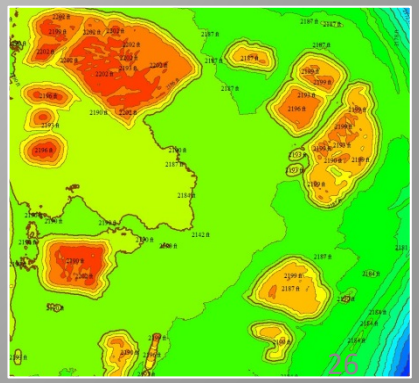


Point Cloud Classification

KML – 3D Modeling

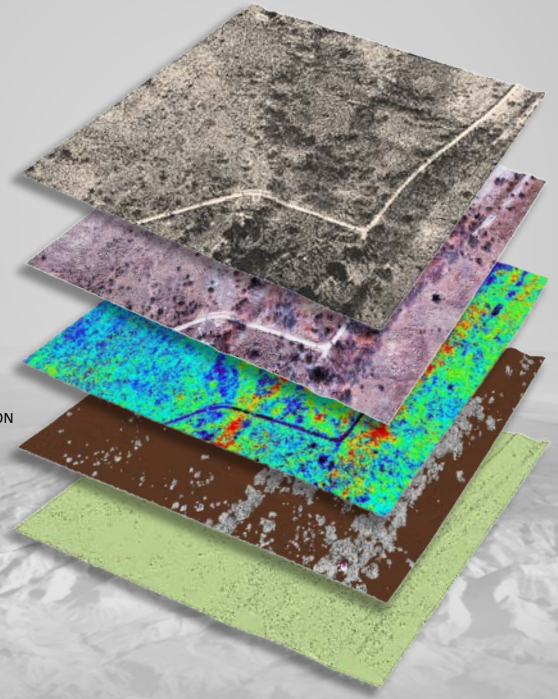
Orthophotography

Volumetric Measurements



Contour Generation

Derived Geospatial Products



3-D POINT CLOUD DATA

DIGITAL SURFACE MODELS

DIGITAL TERRAIN MODELS

ORTHOIMAGERY

SEGMENTATION AND CLASSIFICATION

Outline

- How to make it work
  - **What are the rules to legally fly within the National Airspace**?
  - Safety, cost savings, and better data?
  - Proof-of-concept missions over the past 5 years

Policies: How to Operate in the United States National Airspace

- **Certificate of Authorization (COA):**
  Authorization or waiver issued by the Air Traffic Organization to a public operator for a specific UAS activity on a case-by-case basis

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- **Memorandum of Agreement (MOA) – 'Class G Airspace Notification' :**
  - Originally signed Dec. 24, 2013 (updated Sept. 2015)
  - FAA and DOI Information Bulletin No. 14-04
  - Up to 1,200' AGL
  - Visual Line of sight
  - 5 nm from an airport (control tower)
  - 3 nm from an airport (published instrument procedures)
  - 2 nm from an airport (not having published instrument procedures)
  - 2 nm from a heliport
  - Not over people or urban settings
  - NOTAM
  - VFR weather minimums
  - Allowed to fly at night

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Policies: How to Operate in the United States National Airspace

- **FAA Part 107 – Small Unmanned Aircraft Rule**

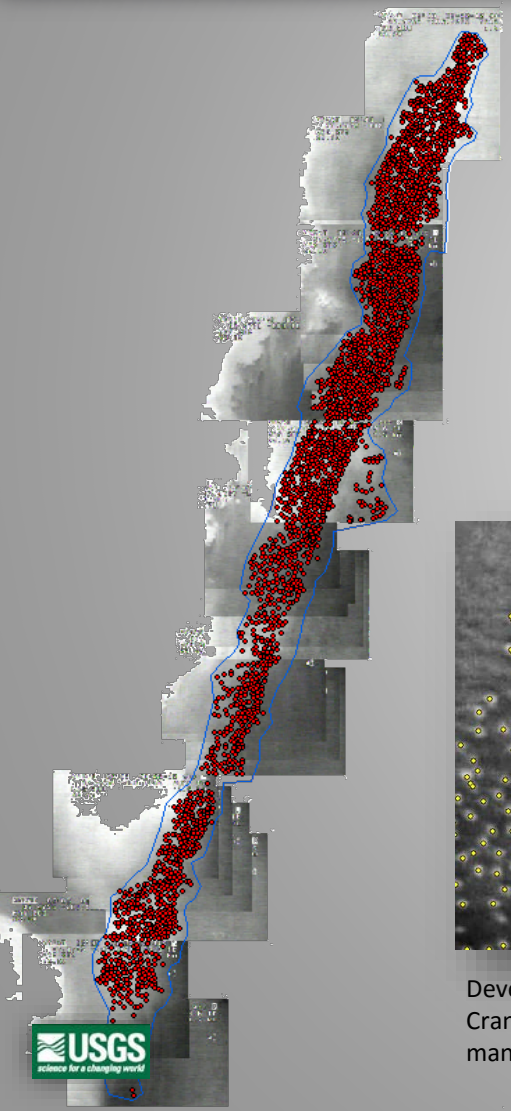
  - Announced June 21, 2016 to go into effect August 29, 2016
  - Under 25 kg (55 lbs)
  - Visual line-of-sight
  - May not operate over persons not directly participating in the operation
  - Daylight only operations (30 min. before sunrise, 30 min. after sunset)
  - Visual observer is not required
  - Max speed = 100 mph
  - Max altitude = 400 feet above ground level
  - Operation in Class B, C, D and E airspace are allowed with ATC permission
  - Operation in Class G airspace are allowed without ATC permission
  - Certification:
    - Operator must hold a remote pilot airman certificate
    - Pass an aeronautical knowledge test at a FAA-approved testing center
    - Vetted by TSA
    - Be at least 16 years old

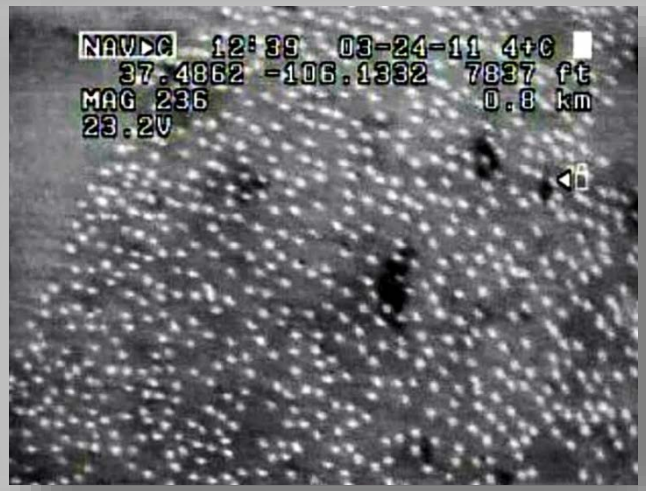
Outline

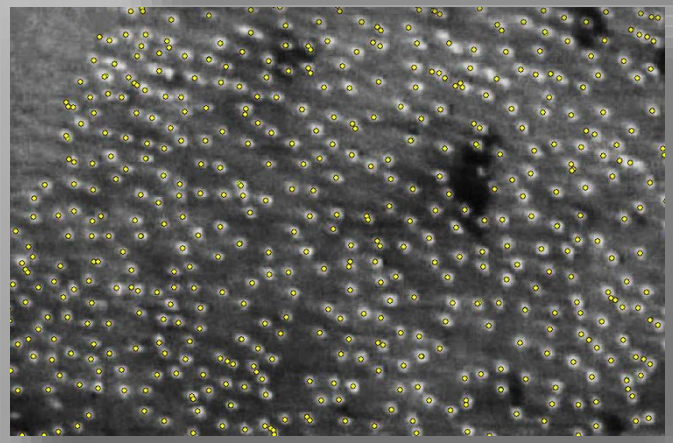
- How to make it work
  - What are the rules to legally fly within the National Airspace?
  - **Safety, cost savings, and better data?**
  - **Proof-of-concept missions over the past 5 years**

Sandhill Crane Population Estimates

Monte Vista NWR, Colorado – First UAS Mission in the National Airspace - March 2011





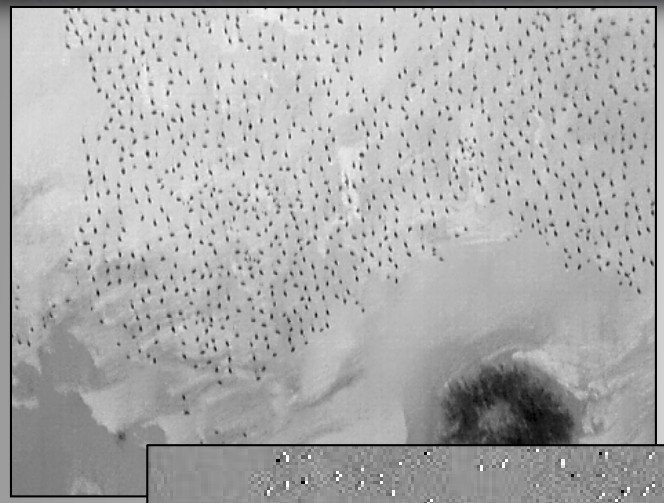


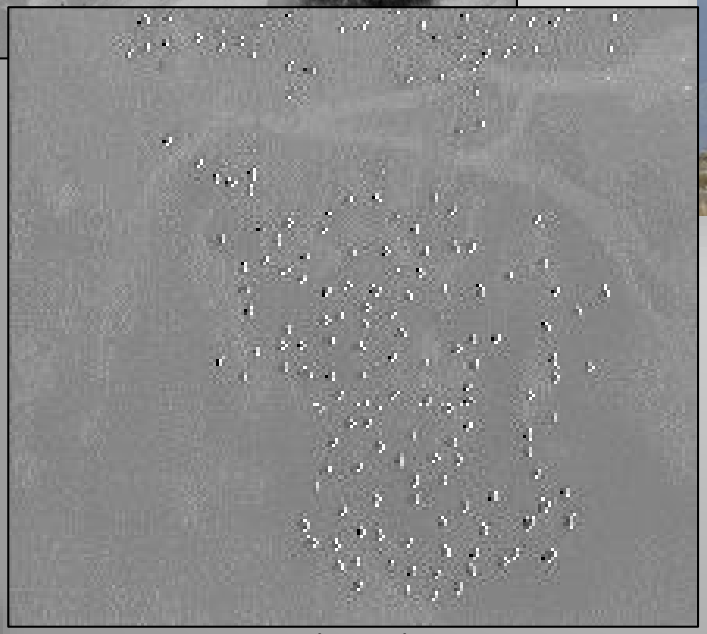
Developing methods to estimate Sandhill Crane abundance for natural resource management.

First operations of the Raven RQ-11A in the National Airspace. Flown at civil twilight using the stock thermal video sensor

Sandhill Crane Population Estimates

Monte Vista NWR, Colorado — March 2016





FLIR Tau 640 Thermal Images

Trumpeter Swan Nesting

Camas and Greys Lake NWR, Idaho

EO camera @400ft AGL from Canon s100 12MP

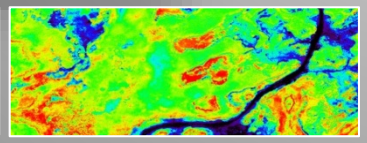
Tau 640 thermal-IR @400ft AGL from RAW 14-bit

Waterfowl & Habitat Surveys

Ruby Lake, NV – Kern/Pixley, CA – Tomalas Bay, CA

Generating a census for waterfowl populations and determining individual species. Developing an UAS image library for waterfowl identification and mapping habitat.

From 1937 to 2000, 66% of all field biologist fatalities in DOI were aviation-related.



15 cm ZOOM					
Elevation (MASL)	158	138	120	102	85
M above ground	90	70	52	34	17
Ft above ground	295	229	170	112	56
Mallard					

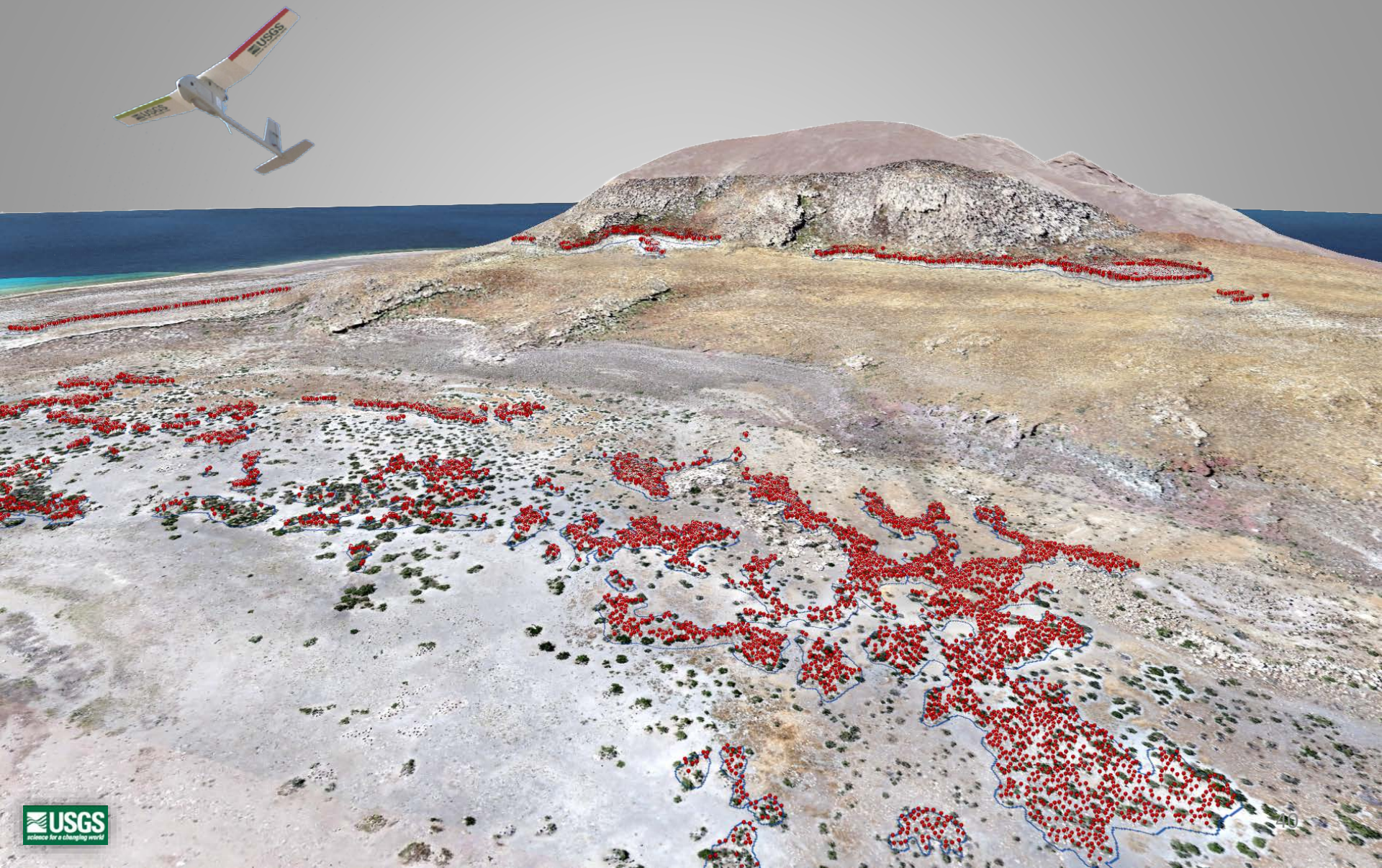
Pelican Nesting Habitats

Chase Lake, North Dakota June 2014

Raven UAS image mosaic from the Sony ActionCam (2mp) from 400 ft. AGL

Pelican Nesting Habitats

Pyramid Lake - Reno, Nevada 2014



Elk Population Surveys

Carrizo Plain, California

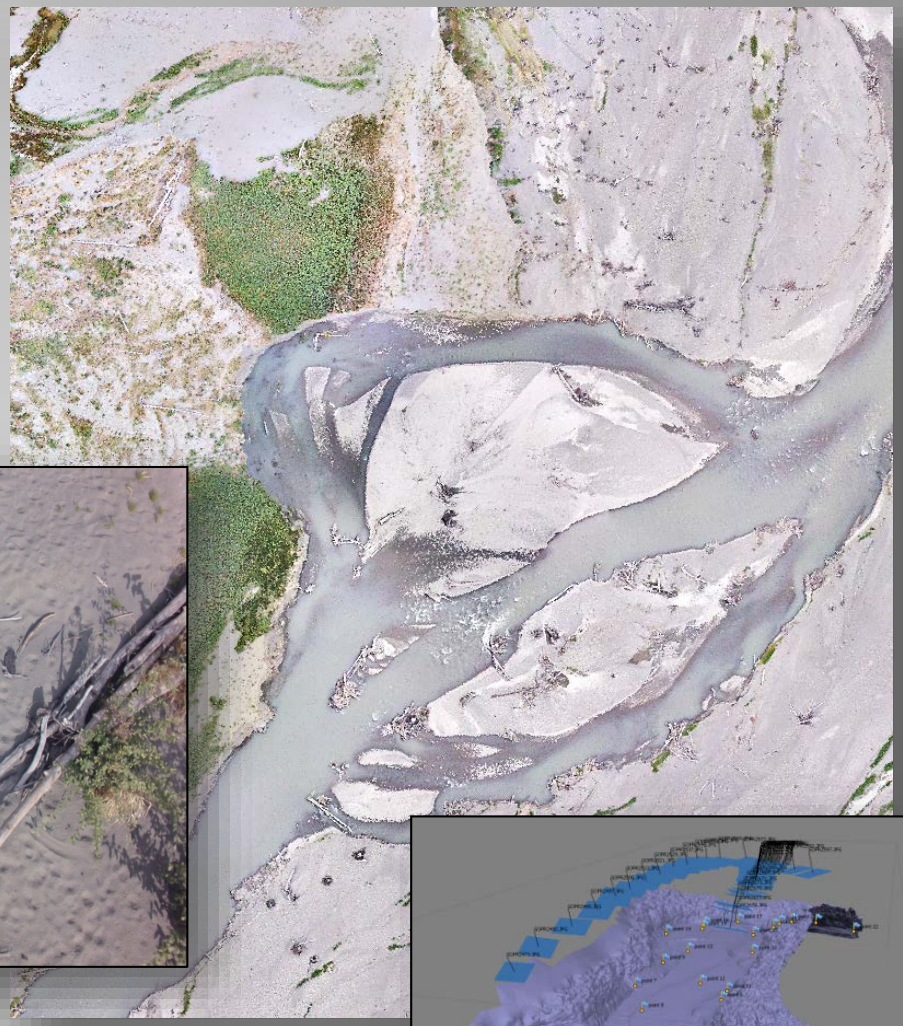
Raven UAS individual images from the Sony ActionCam (2mp) from 150 ft. AGL

Elk Population Estimates

Idaho 2015

Elwha Dam Removal and River Restoration

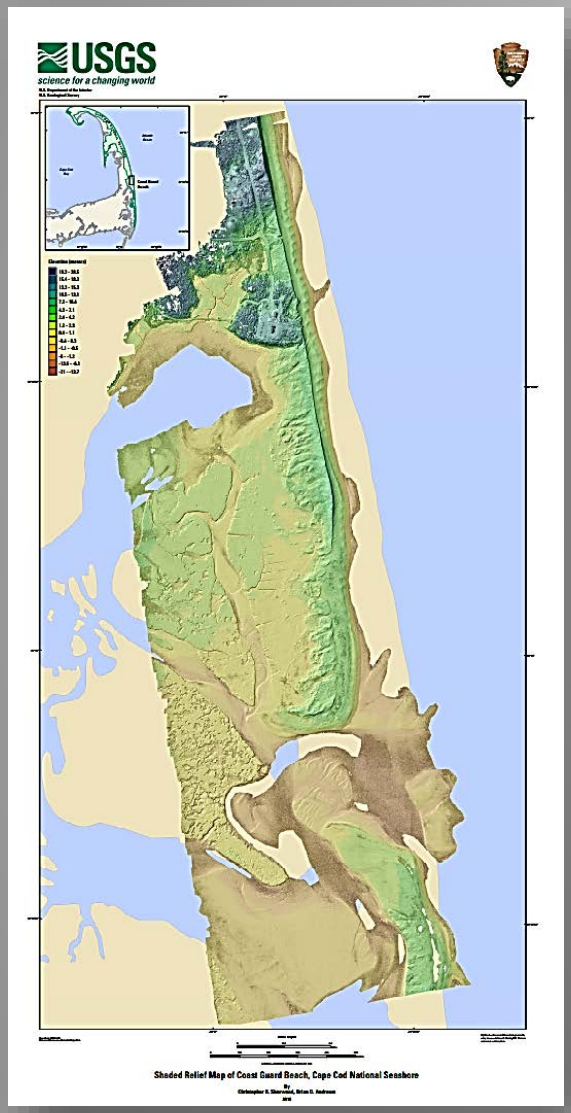
Olympic National Park, Washington 2012



Monitoring sediment volumes eroded from the reservoir and deposited downstream, where the mobile sediment can potentially affect salmon habitat.

Coastal Applications

Cape Cod National Seashore, 2016



Shaded Relief Map of Coast Guard Beach
Cape Cod National Seashore
Sherwood & Andrews 2016

Overwash and erosion along beaches of Sandwich, Mass
Sherwood & Traykovski 2016

USGS
science for a changing world

Coastal Applications

Archie Carr National Wildlife Refuge – Florida
Nesting sea turtle tracks

Burgess, et al 2015

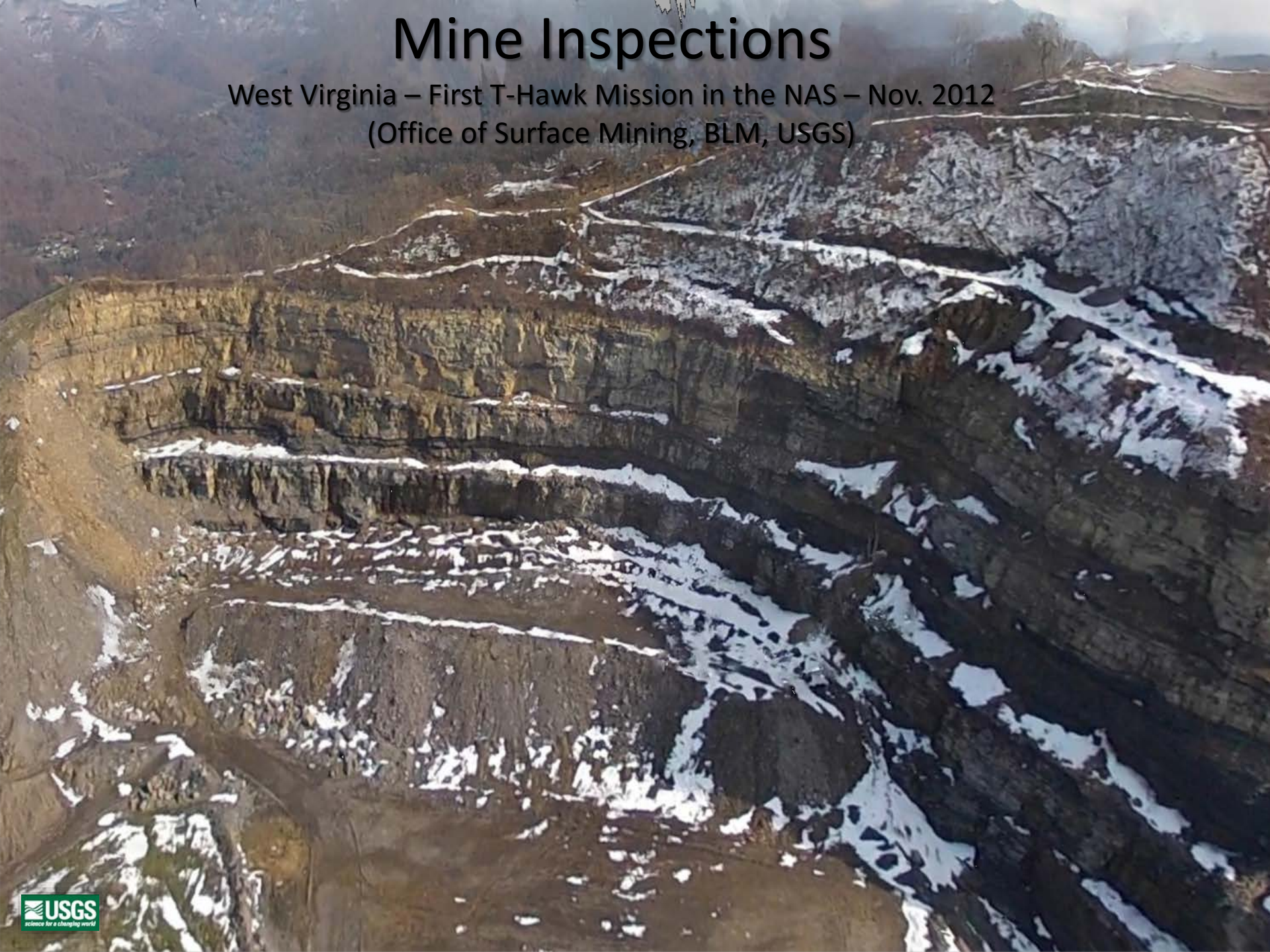
Mine Inspections

West Virginia – First T-Hawk Mission in the NAS – Nov. 2012 (Office of Surface Mining, BLM, USGS)

Mine permit inspections monitoring a range of topics:
water quality, hazardous conditions, terrain topology, wildlife habitats, erosion, check dams, and post mining land use

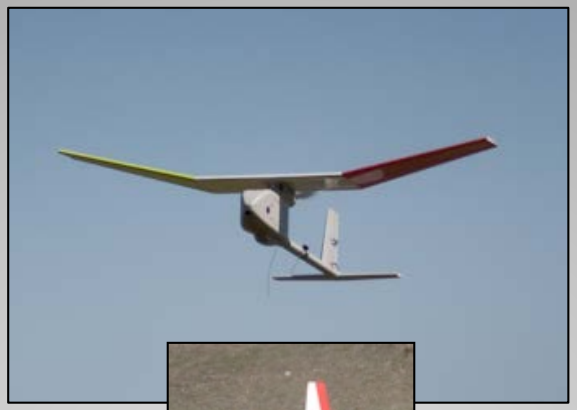
Mine Inspections

West Virginia – First T-Hawk Mission in the NAS – Nov. 2012
(Office of Surface Mining, BLM, USGS)



Monitoring Mining Areas

Lead Mine Sinkholes, Missouri



Abandoned Mine Lands, Colorado

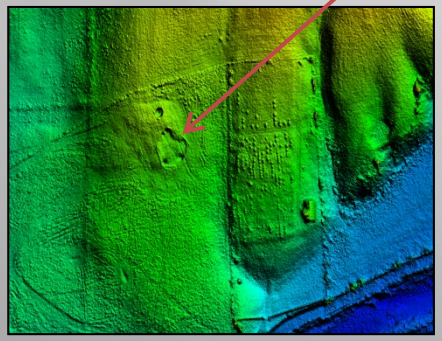
Coal Mine Reclamation Monitoring, West Virginia

West Fork Lead & Zinc Mine (Sinkholes)

Bunker, Missouri

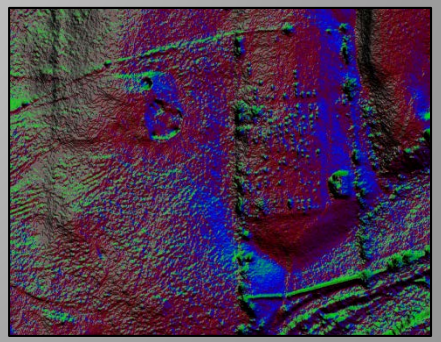
Sinkholes

Orthoimagery



Elevation

Slope



Aspect

Flying at 325 feet (100 m) Above Ground Level - 2 cm GSD - 2 cm horizontal accuracy and 4 cm vertical

Utilization of Small Unmanned Aircraft Systems for Acquiring High-Resolution Elevation Data

West Fork Lead and Zinc Mine near Bunker, Missouri

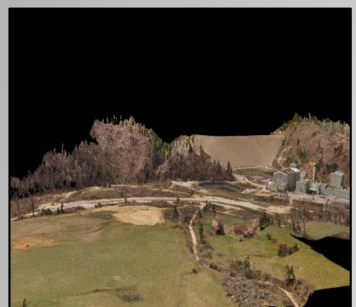
April 2016

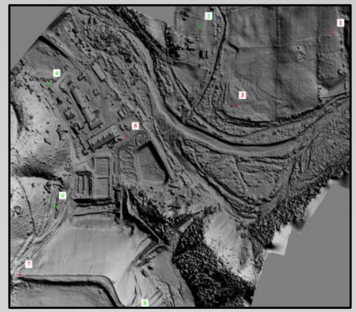
DJI Inspire with dual cameras on-board (Zenmuse X3 and Ricoh GR)
Flown by the USGS contracted to 417 Drone Imaging, Springfield, MO

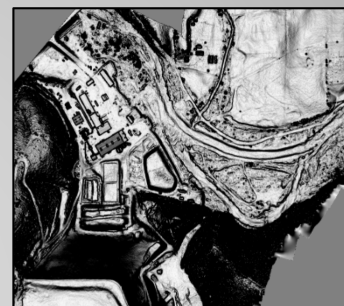
Eight RTK Level GPS points were surveyed by the USGS Rolla, MO

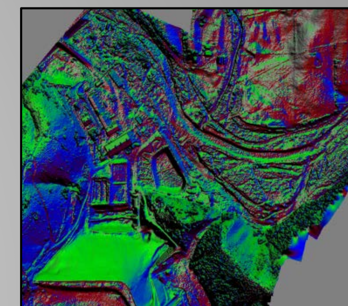
ORTHOPHOTO MOSAIC | **DENSE POINT CLOUD** | **DIGITAL SURFACE MODEL** | **SLOPE VALUES** | **SLOPE ASPECT**

DJI Inspire – Zenmuse X3

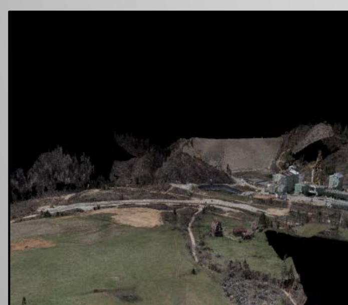


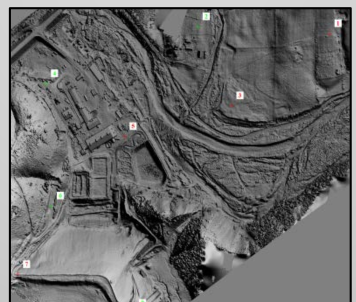


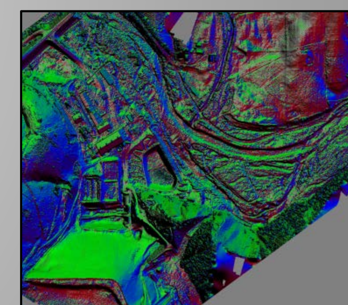


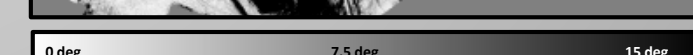


DJI Inspire - Ricoh GR









Utilizing the DJI-Inspire UAS Platform with an on-board Zenmuse X3 FC350 12-megapixel camera and a Ricoh GR camera 16-megapixel camera for simultaneous still frame image collection, two separate three-dimensional models were created using Agisoft Photoscan (v. 1.2.4.2399) to derive the geospatial data. Flying at an approximate height of 325 ft. (100 m) above ground level in four separate flights, a ground sample distance of 5.18 cm (pixel) with the Zenmuse camera, and 3.42 cm (pixel) with the Ricoh GR camera were achieved.

	# of Images	GPS Pts.	Check Pts	GSD (cm)	Area Cover. (Km²)	Fly Alt (m)	Reproj. Err (pix)
DJI Zenmuse	1047	4	4	5.18	1.29	100	0.42
Ricoh GR	1046	4	4	3.42	1.11	100	0.312

The dense point cloud generated from the images generate the color values assigned to the x,y and z coordinate values to create a realistic modeled representation of the study area. The structure-from-motion software is capable of generating several hundred million points from the correlated images.

	# of Images	Pts. Generated	# of Faces Generated	Resolution (cm)	Density (pts/m²)
DJI Zenmuse	1047	156,025,358	10,328,850	10.4	90
Ricoh GR	1046	244,335,244	18,136,495	6.83	216

The two digital elevation models derived from the simultaneous collects of 1046 images resulted in accuracies noted in the following charts when compared to four independent ground GPS (RTK level) checkpoints shown in green.

DJI Zenmuse

Name	ΔEasting	ΔNorthing	(ΔEasting)²	(ΔNorthing)²	(ΔEasting)² + (ΔNorthing)²	ΔElevation	(ΔElev)²
Target02	-0.0679	-0.1298	0.0046	0.0167	0.0213	0.1428	0.0204
Target04	0.1021	-0.8908	0.0104	0.7935	0.8042	0.1395	0.0197
Target06	0.1186	-0.2841	0.0141	0.0807	0.0948	-0.0290	0.0008
Target08	-0.5175	0.0800	0.2678	0.0065	0.2607	[illegible]	0.0071
				Sum	1.1808	Sum	0.1548
				Average	0.2972	Average	0.0387
				RMSE	0.5452	RMSE	0.1967
				NSSDA	0.9435	NSSDA	0.3855

Ricoh GR

Name	ΔEasting	ΔNorthing	(ΔEasting)²	(ΔNorthing)²	(ΔEasting)² + (ΔNorthing)²	ΔElevation	(ΔElev)²
Target03	0.0476	0.0136	0.0023	0.0002	0.0024	0.1868	0.0349
Target04	-0.0501	0.0842	0.0025	0.0071	0.0096	0.1795	0.0322
Target06	-0.0084	0.0588	0.0001	0.0035	0.0036	-0.1090	0.0119
Target08	-0.1408	0.1880	0.0198	0.0353	0.0550	-0.2406	0.0579
				Sum	0.0699	Sum	0.1370
				Average	0.0175	Average	0.0342
				RMSE	0.1323	RMSE	0.1850
				NSSDA	0.2272	NSSDA	0.2941

Slope values can be compared at the specific target points to get a general idea of the similarities or differences in the way the surface models are derived and the assurance of accurate data when used for geospatial studies. The number of triangulated faces or the mesh generated, and the specific algorithms can have a varying degree of results on the model. Below is a comparison of the two cameras.

Ricoh GR		DJI Zenmuse	
Name	Slope Value (Degrees)	Slope Value (Degrees)	Diff. Slope Value (Degrees)
Target 1	3.47	1.98	1.49
Target 2	7.09	6.63	0.46
Target 3	3.94	2.17	1.77
Target 4	1.17	3.46	-2.29
Target 5	1.90	2.81	-0.91
Target 6	4.03	2.78	1.25
Target 7	10.51	0.25	10.26
Target 8	10.99	23.28	-12.29

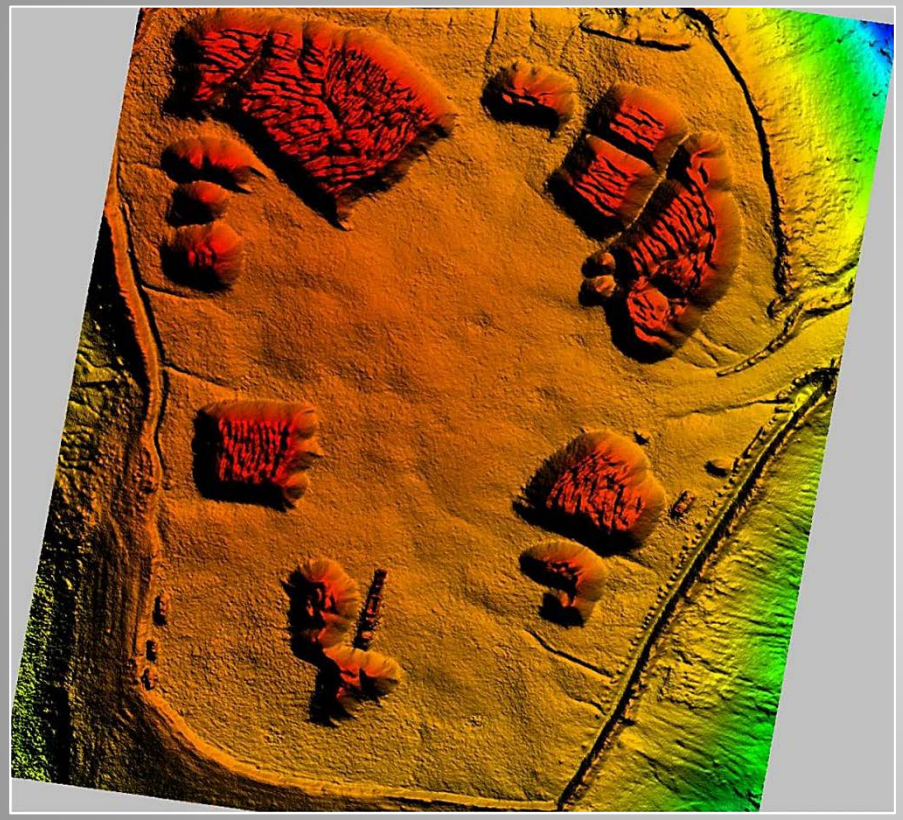
Slope aspect can be compared at the specific target points to get a general idea of the similarities or differences in the way the surface models are derived and the assurance of accurate data when used for geospatial studies. The number of triangulated faces or the mesh generated, and the specific algorithms can have a varying degree of results on the model. Below is a comparison of the two cameras.

Ricoh GR		DJI Zenmuse	
Name	Slope Aspect (Deg. 0-360)	Slope Aspect (Deg. 0-360)	Diff. Slope Aspect (Degrees)
Target 1	260	261	1
Target 2	87	98	11
Target 3	177	222	45
Target 4	360	15	15
Target 5	123	5	118
Target 6	203	143	60
Target 7	30	89	59
Target 8	55	80	25

Jeff Sloan, Todd Burton, Mark Bauer, Josip Adams - U.S. Geological Survey, National Unmanned Aircraft Systems Project Office, Joseph Richards, U.S. Geological Survey – Missouri Water Science Center

Mining Stockpile Volumetric Measurements

Kentucky – 2014

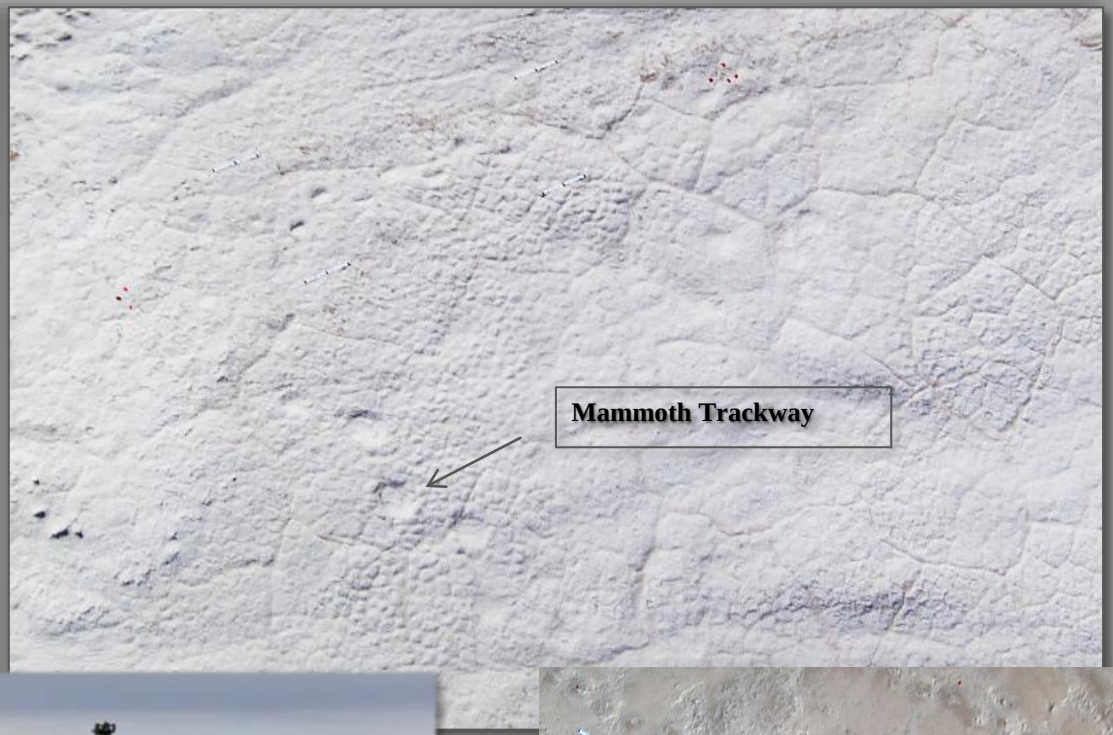


Digital Elevation Model Hillshade

Volumetric Measurements (Cubic Yards)

Pleistocene Trackway Mapping

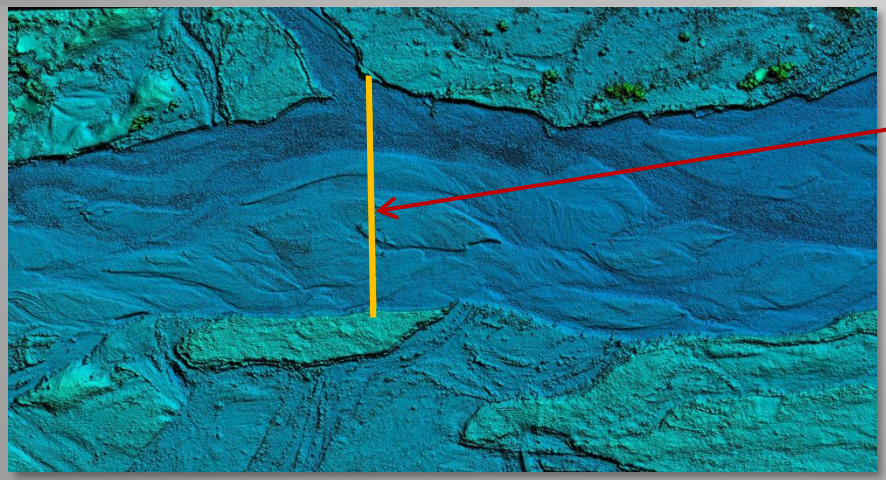
White Sands National Monument, NM January 2014
(BLM & NPS)

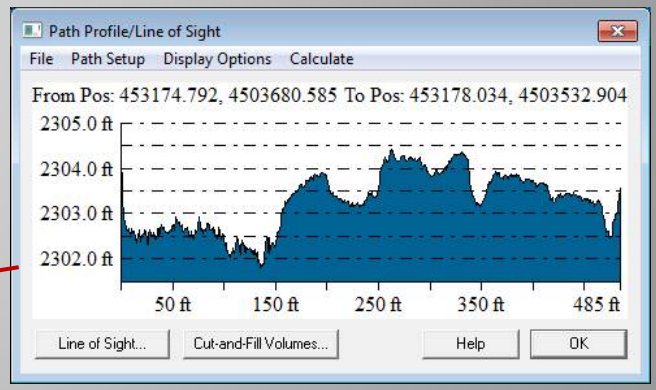


Photogrammetric documentation using a UAS to aerial survey extremely fragile fossilized footprints from the late ice age.

Emergent Sandbar Habitats

Platte River - Kearney, Nebraska





Mapping the spatial extent and elevation of emergent sandbars along two reaches of the Platte River for endangered or threatened nesting birds (least terns and piping plovers)

Debeque Landslide

Debeque, Colorado 2013

June 2013

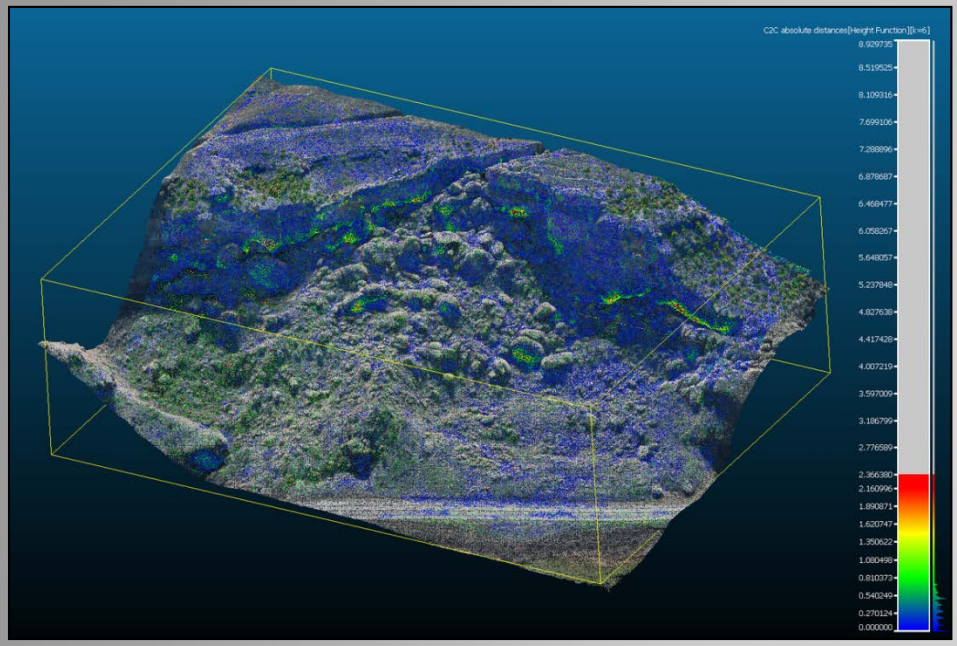
October 2013

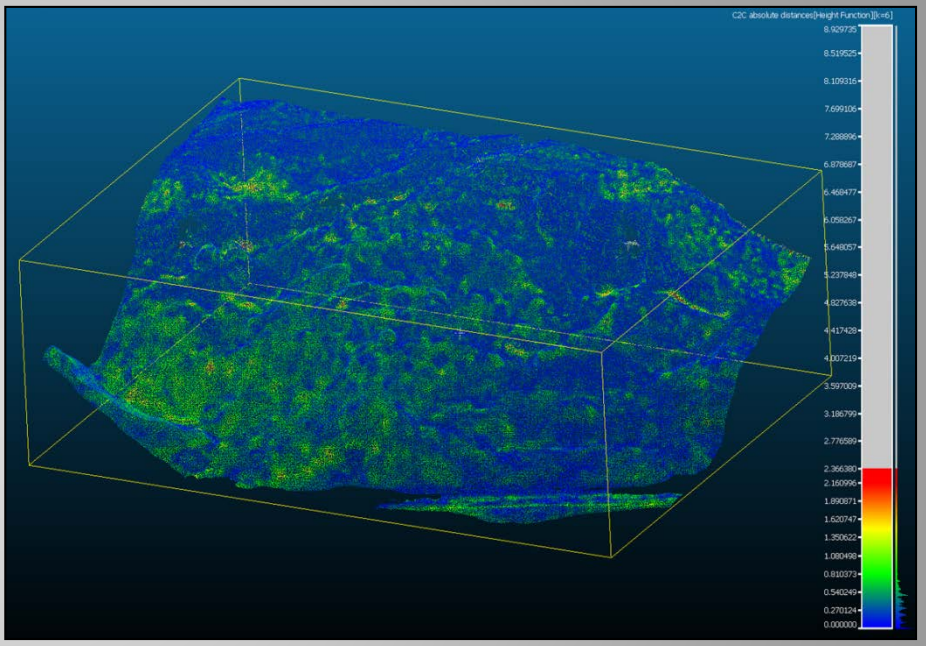
Temporal series of Landslide models monitoring geomorphic processes.

USGS science for a changing world

Debeque Landslide

Debeque, Colorado 2013



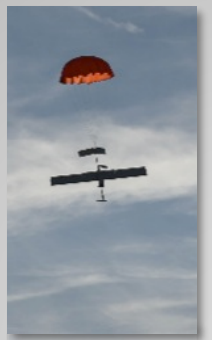


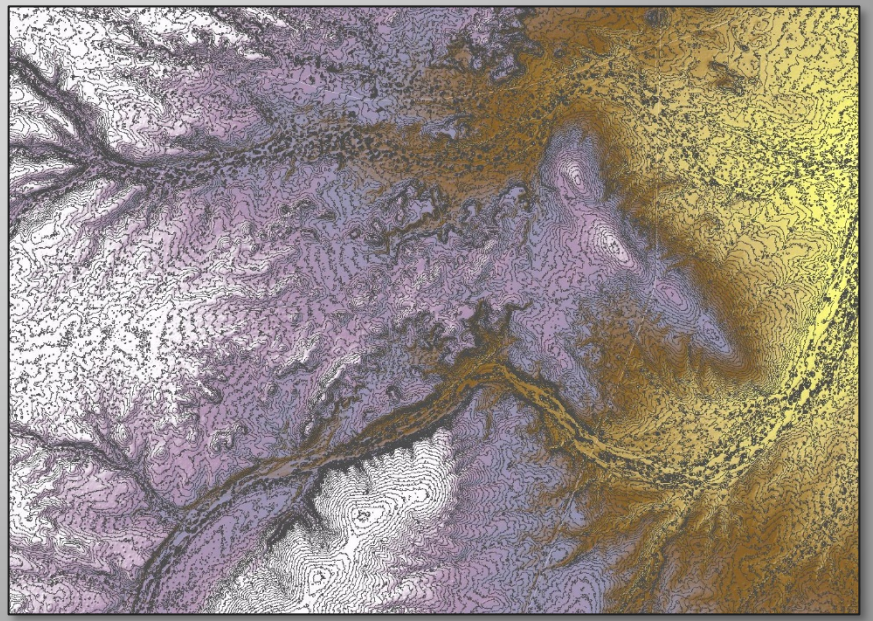
Green indicates possible movement over time

Point cloud comparison and calculations (using Cloud Compare)

Paleowetland Deposit Study Site

Mojave Desert, California

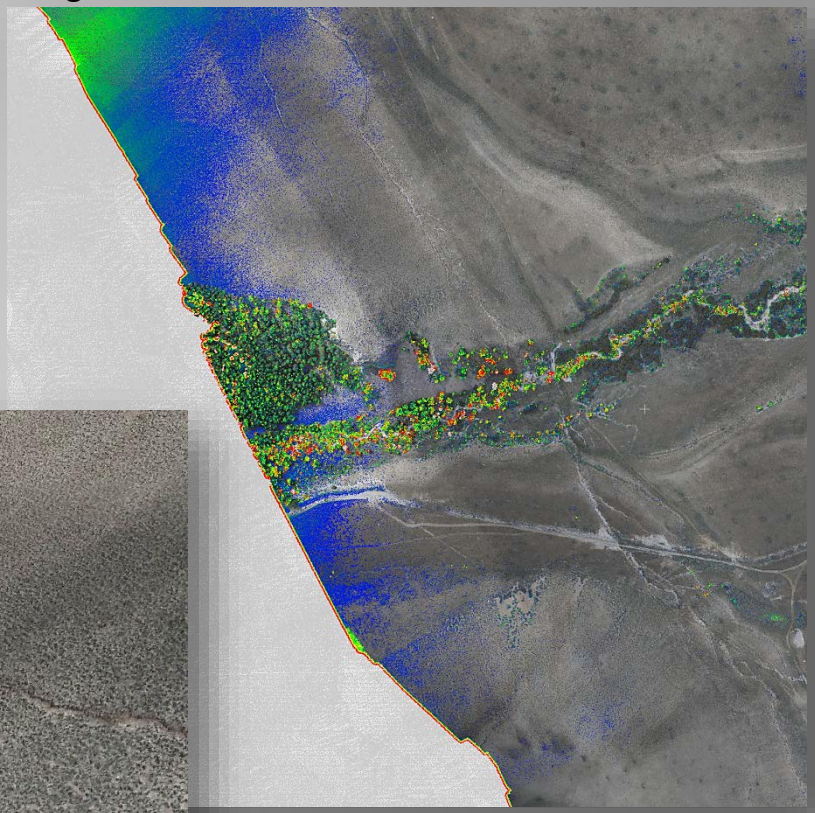




Earthquake Fracture Modeling

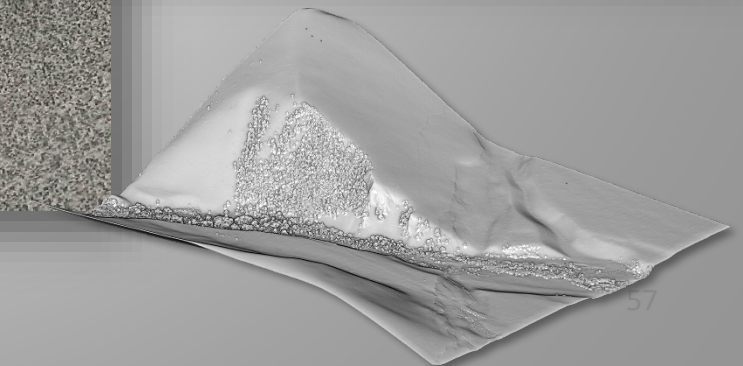
Borah Peak, Idaho

Comparisons between UAS Photogrammetric Point Cloud generation and Airborne LiDAR



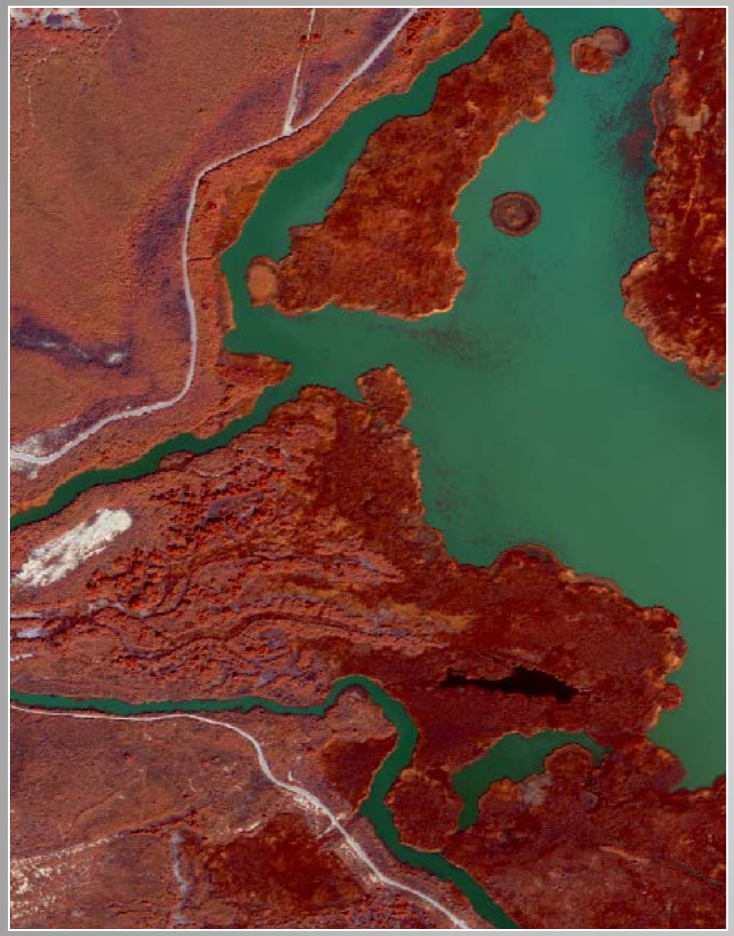
Colors indicate a 6-12” vertical difference

UAS Photogrammetric Point Cloud generated from images taken at 1200 ft. AGL



Lake Havasu, Arizona

October 2014



WorldView 2 – Multispectral (pan sharpened)

UAS – Canon s100 (modified blue filter)

Lake Havasu, Arizona

October 2014

WorldView 2 – Multispectral (pan sharpened)

UAS – Canon s100 (modified blue filter)

UAS Data Processing

Color Infrared & Normalized Difference Vegetation Index (NDVI)

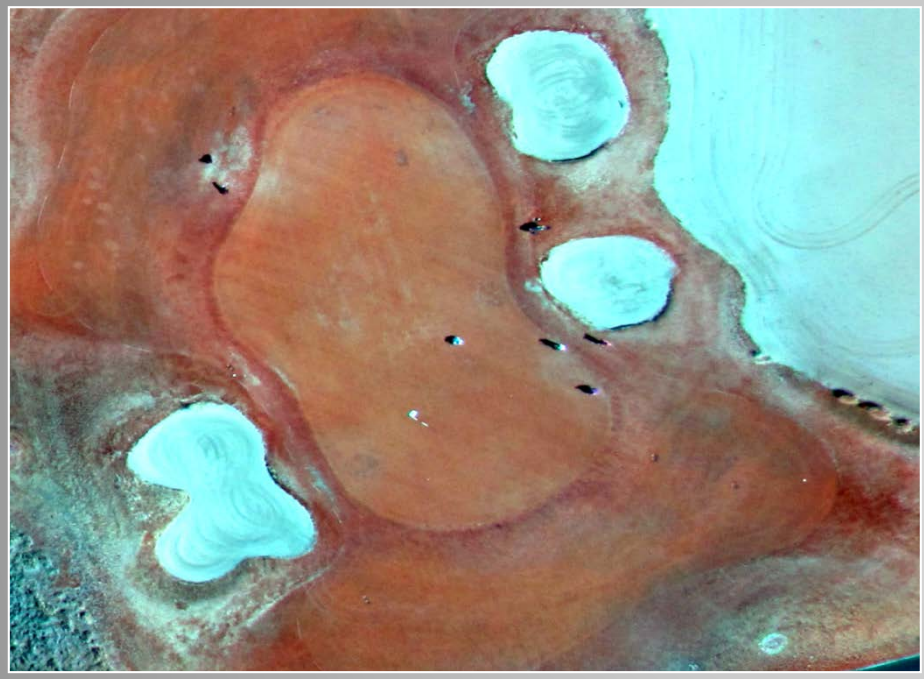
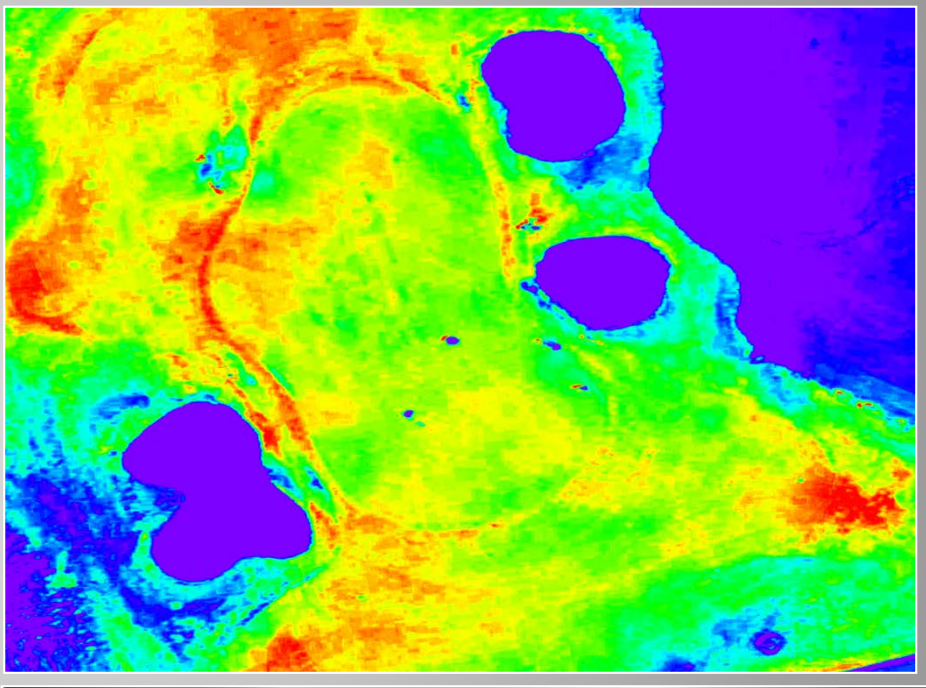


Image collected from UAS – Canon SX230 HS – 400’ AGL



NDVI Low NDVI High

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{VIS})}{(\mathrm{NIR} + \mathrm{VIS})}$$

Theodore Roosevelt National Monument

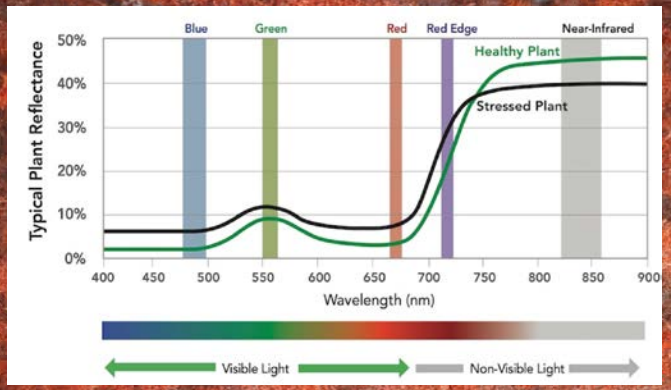
North Dakota – Aug. 2016

Sony A5100
Voigtlander Lens 15 mm
RGB (Bayer Filter)

Micasense Multispectral
RGB, NIR, Red Edge

Theodore Roosevelt National Monument

North Dakota – Aug. 2016



USGS science for a changing world

Theodore Roosevelt National Monument

North Dakota – Aug. 2016

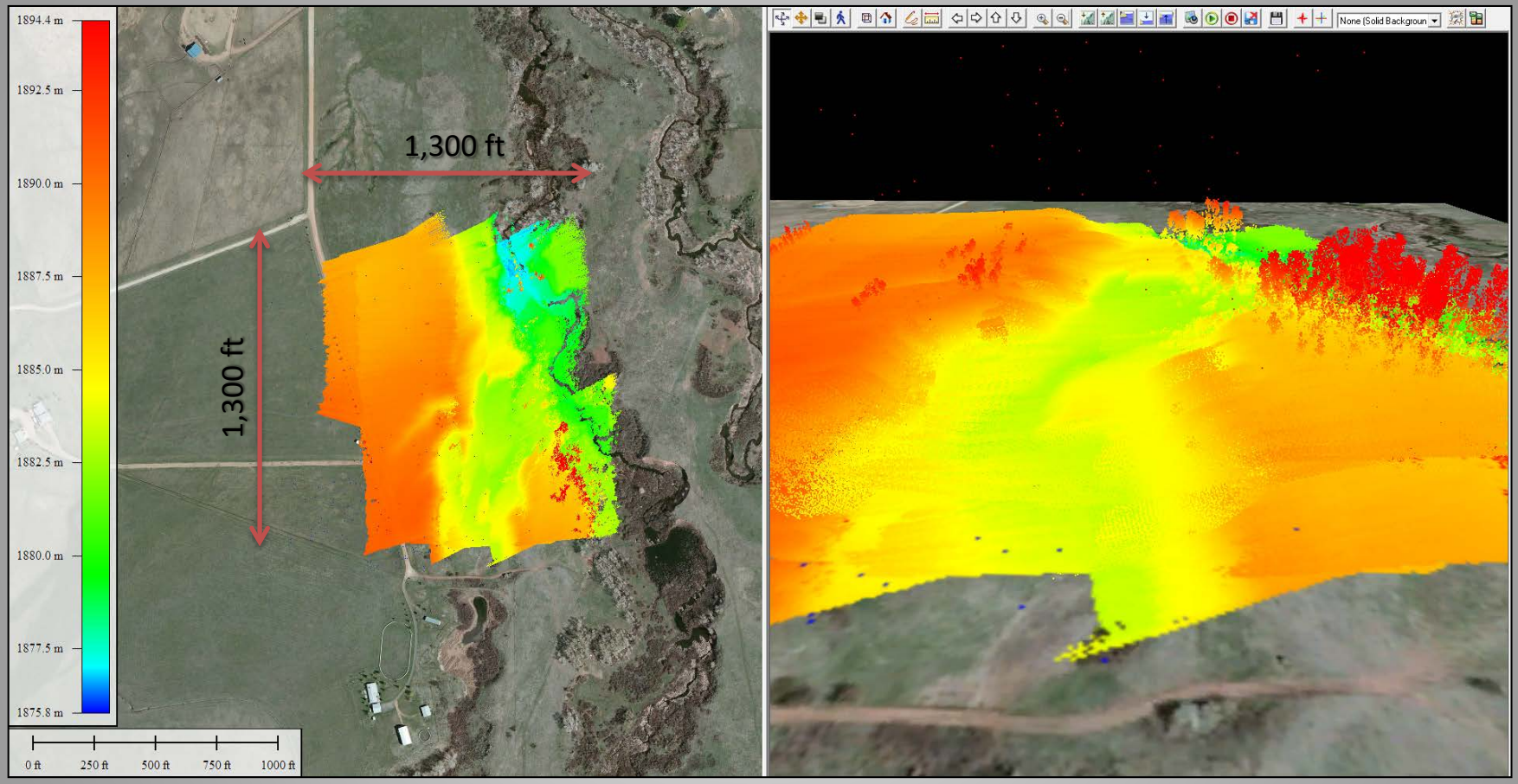
USGS science for a changing world

Micro UAS – 3DR Solo

Image courtesy 3DR

Sensor Testing and Integration

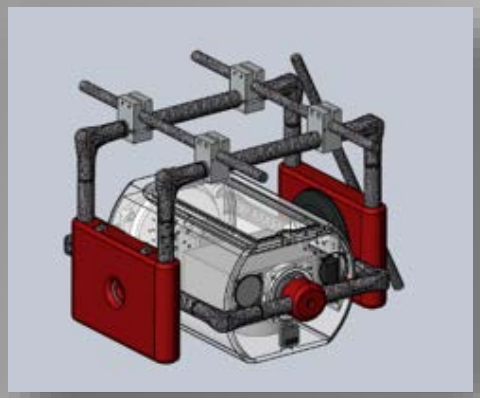
Colorado 2016



Pulse Vapor 55 UAS

Multiple Payload Capability
(Simultaneous Data Collection)

Cooperative Work - Academia



2-Axis Gimbal Setup

EO, TIR, hyperspectral and lidar sensors

UF UNIVERSITY of FLORIDA — Unmanned Aircraft Systems Research Program

USGS science for a changing world

High Altitude Pseudo Satellite (HAPS)

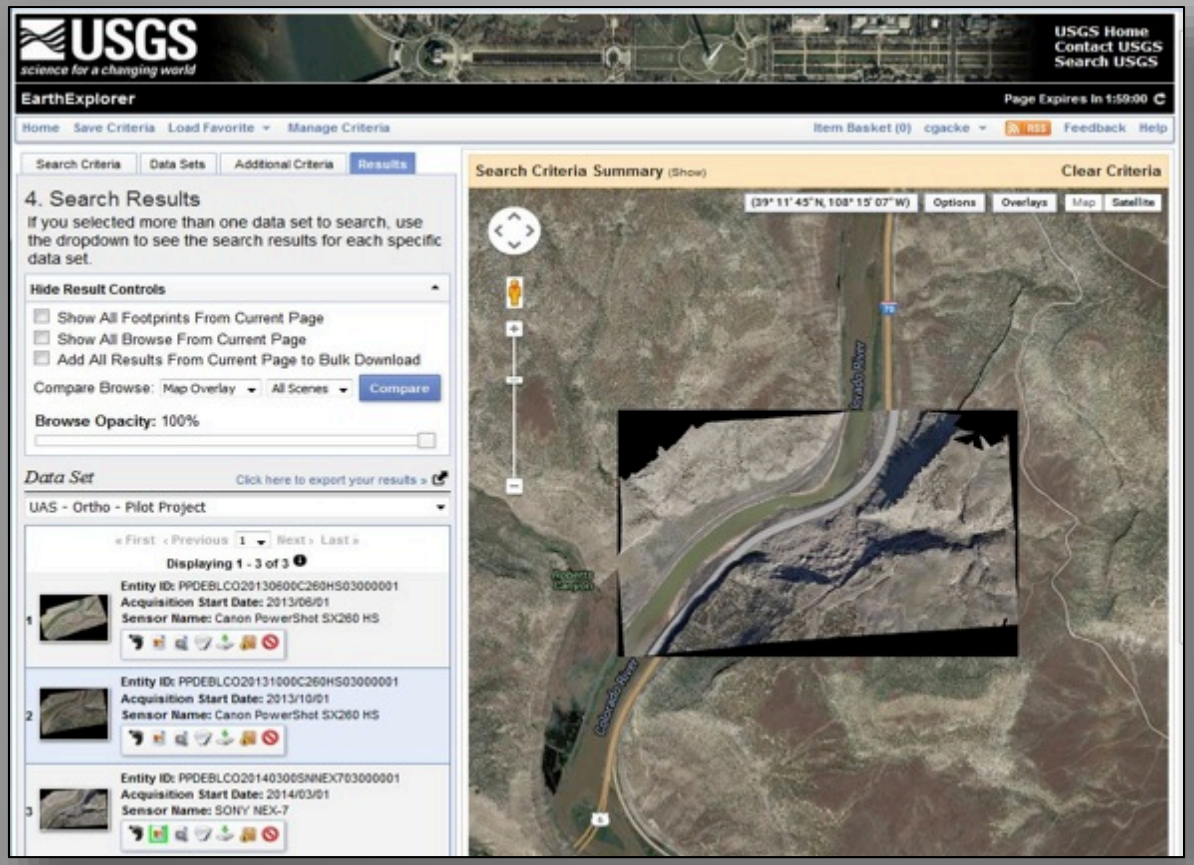
- High Altitude Pseudo-Satellite (HAPS)
  - Airbus Zephyr UAV
  - Corning nanoSHARK hyperspectral sensor
  - NASA Ames, other sensors (TIR)
  - Spring 2017 workshop
- Western U.S. flights (California)
- Duration: days to weeks to months
- “Call for Ideas” to USGS scientists
  - Received 11 ideas
- NOAA, NASA Langley & Solar Impulse
- Environmental Applications

Can the Work be Contracted?

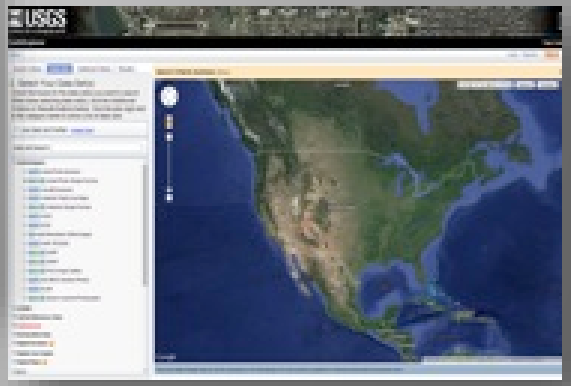
7,500+ Unmanned Aerial Systems with FAA Section 333 Exemptions for Commercial Work

FAA Part 107 - New Rules for Commercial Operators – August 2016

UAS Data Access & Distribution



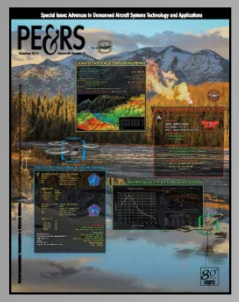
Data archive and management

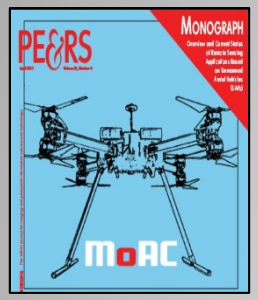


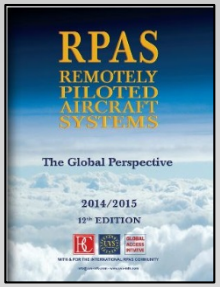
Presidential memorandum:
"Safeguarding Privacy, Civil Rights, and Civil Liberties in Domestic Use of Unmanned Aircraft Systems"

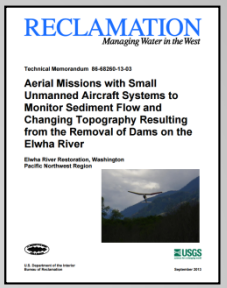
Can UAS Data Be Published?

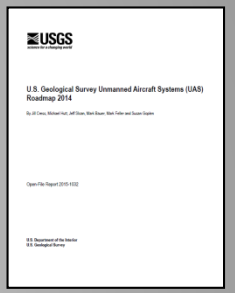
Peer Reviewed Publications:











Mainstream Press:

New York Times, Air & Space, Unmanned Systems International, Earth Imaging Journal
National Geographic, Federal Times, NPR, Several Newspapers

What are the Basic Costs?

Platform → **Cameras Sensors** → **Collect Data** → **Process Data**

$800 - $4,000

$20,000

$80,000+

$300-$1,200

GoPro
Be a HERO.

$2,000 - $10,000

MicaSense

FLIR

$25 - $100/hr

$3,000

PhotoScan
3D Modeling and Mapping
Agisoft

$400

Global Mapper

USGS
science for a changing world

Will UAS Become Just Another Commonly Used Tool in the Scientist Toolbox?

?

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