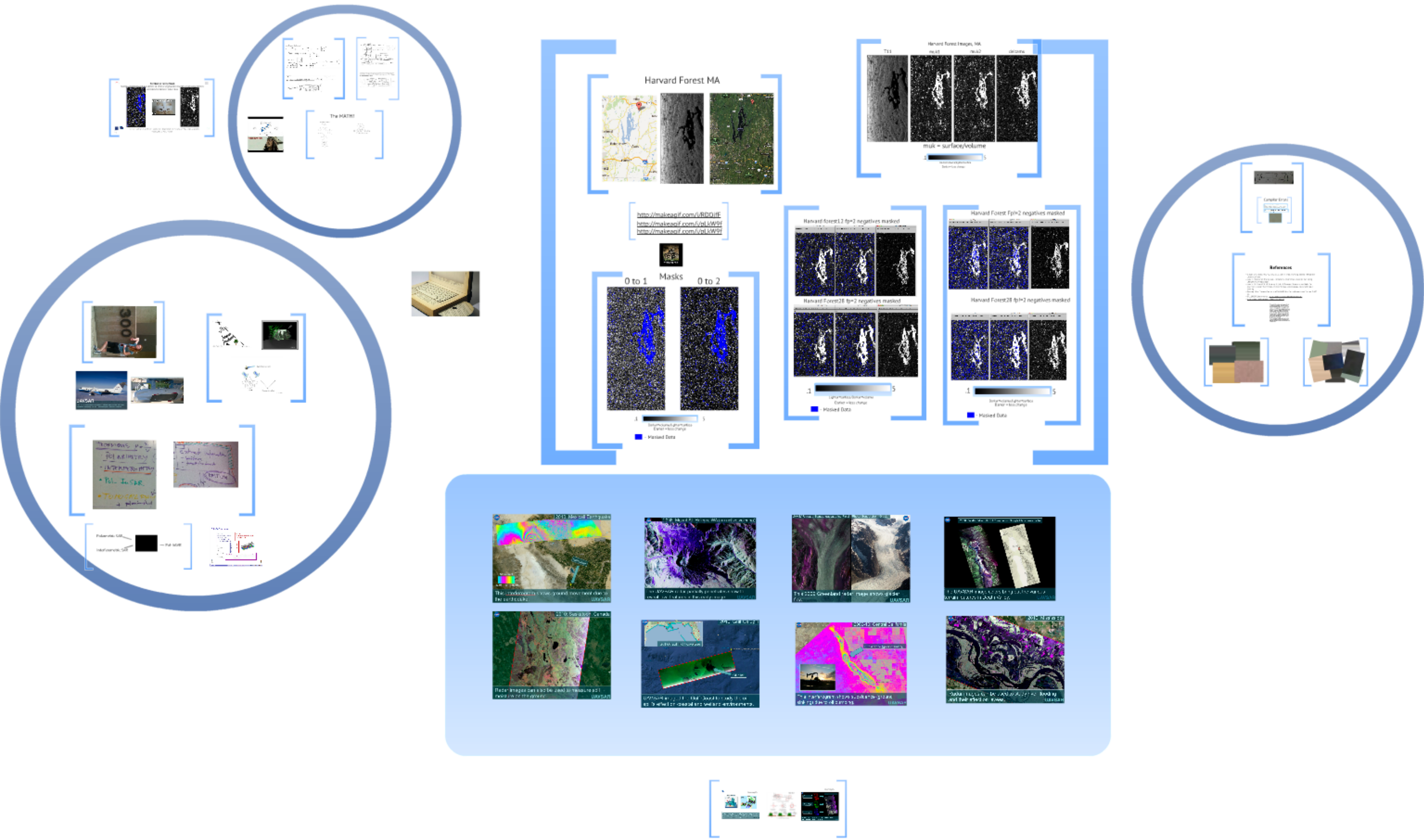
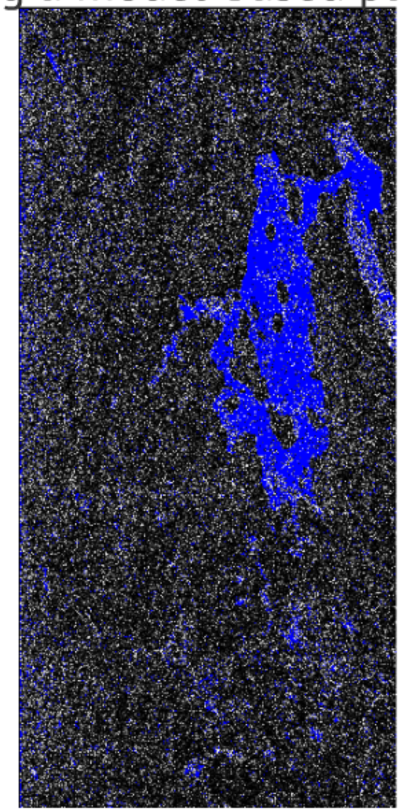

The MATH!
Harvard Forest MA
Masks
0 to 1
0 to 2
Masked Data
Harvard Forest Images, MA
muk = surface/volume
Harvard forest12 fp=2 negatives masked
Harvard Forest28 fp=2 negatives masked
Harvard Forest Fpl=2 negatives masked
Harvard Forest28 fpl=2 negatives masked
References

To Mask or not to Mask:

Using a model-based parameter to detect vegetation changes from polarimetric and interferometric radar data



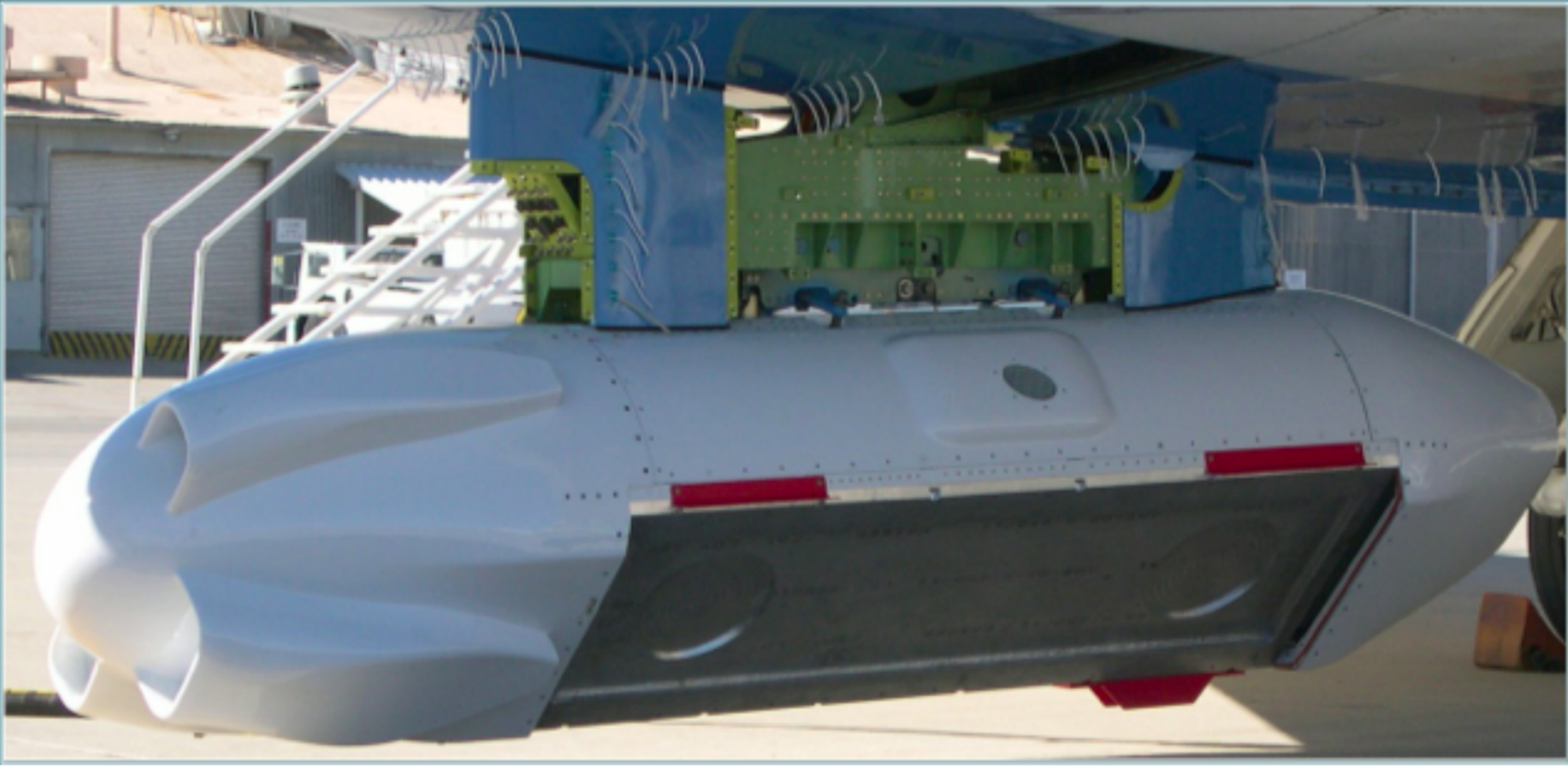
Kaitlyn Fiechtner, STAR (STEM Teacher and Researcher) Intern NASA Jet Propulsion Laboratory
Marco Lavalle, Ph.D., Mentor

Grant No. 0952013

Grant No. 0934967


300
Gov't
Badge

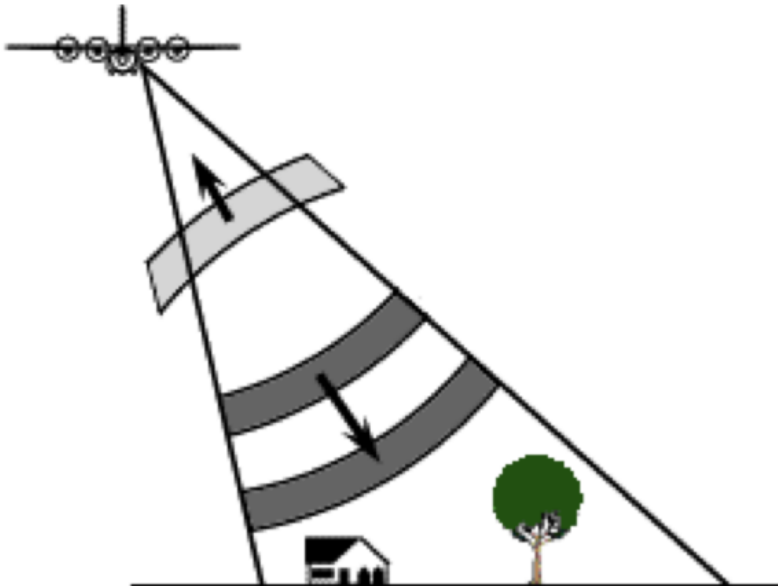

GOAL



UAVSAR

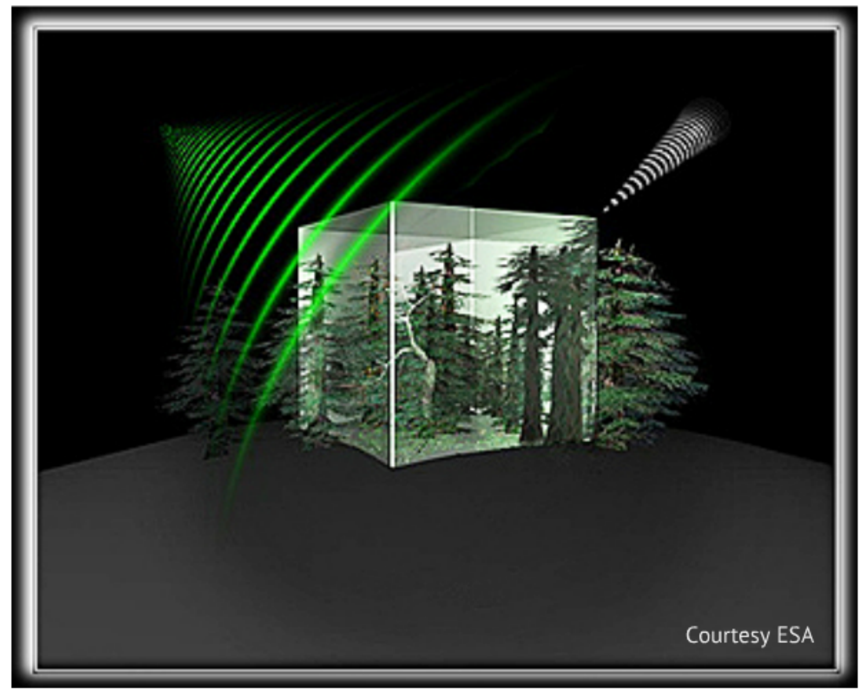
Uninhabited Aerial Vehicle Synthetic Aperture Radar

Using an airborne radar to study earth science (earthquakes, volcanoes, vegetation, hydrology, ice, etc.), with emergency response potential



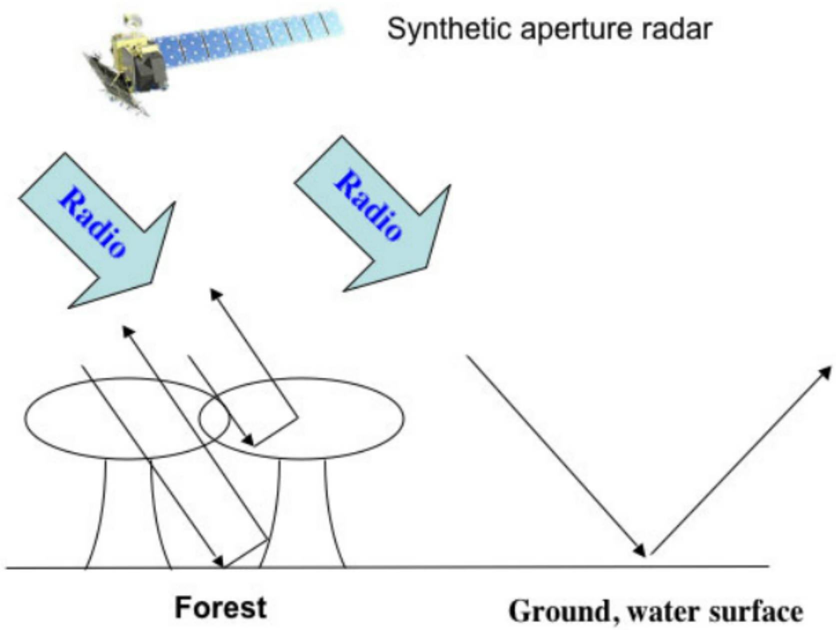
Courtesy JPL

© CCRS / CCT

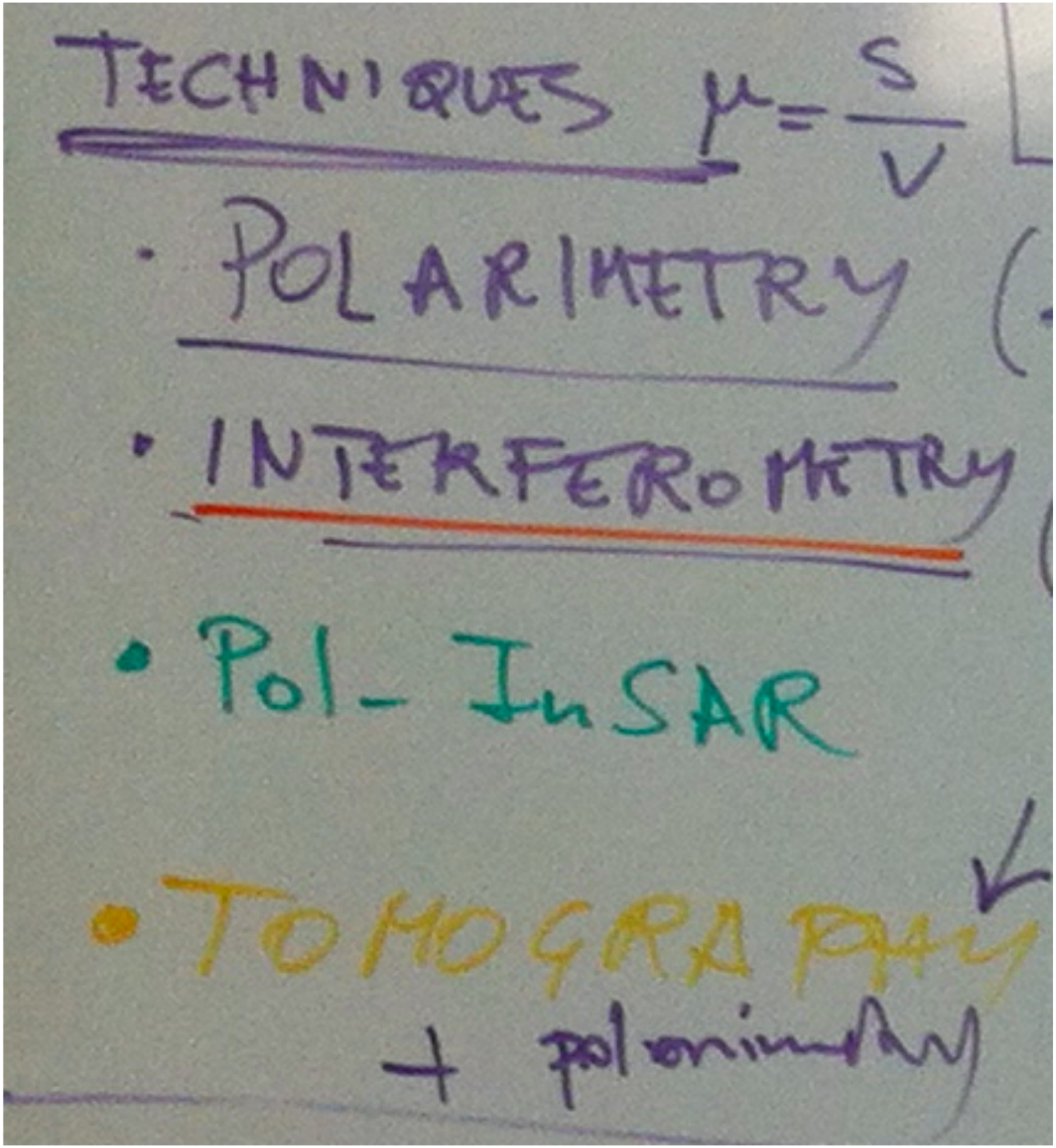


Synthetic aperture radar

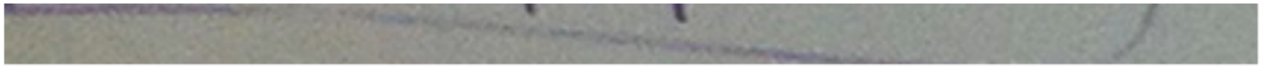
Courtesy JPL

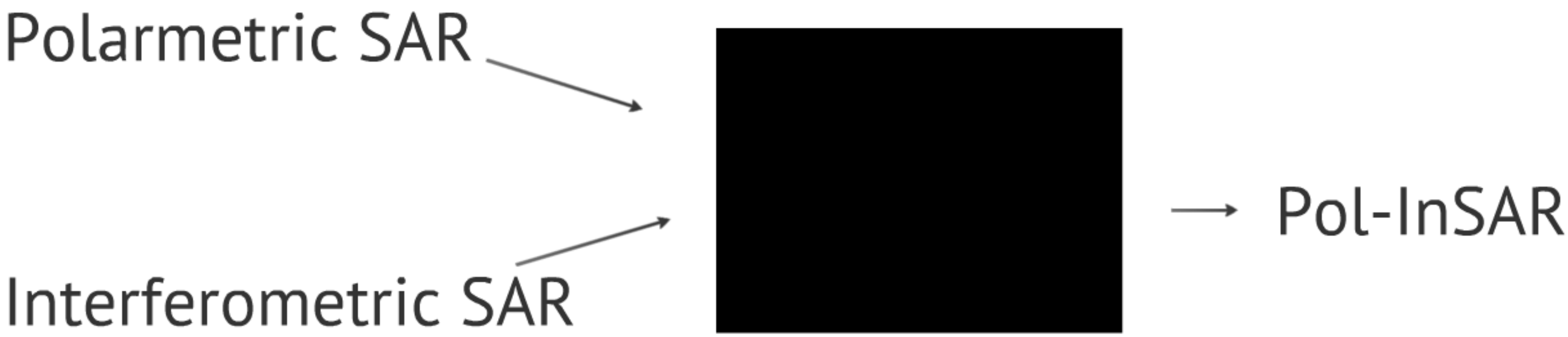


Courtesy of JAXA


TECHNIQUES
μ = s/v
• POLARIMETRY
• INTERFEROMETRY
• Pol-InSAR
• TOMOGRAPHY
+ polarimetry

- INTERFEROMETRY
- Pol-InSAR
- TOMOGRAPHY




Polarmetric SAR
Interferometric SAR
Pol-InSAR

Polarmetric SAR

Interferometric SAR

→ Pol-InSAR

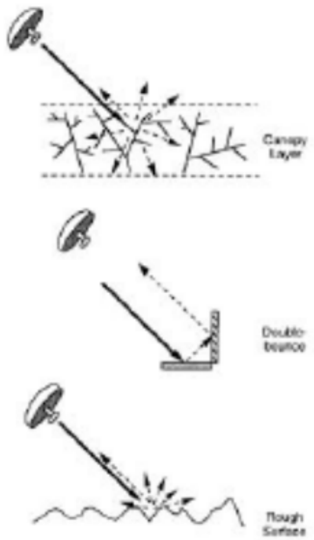
PolInSAR features

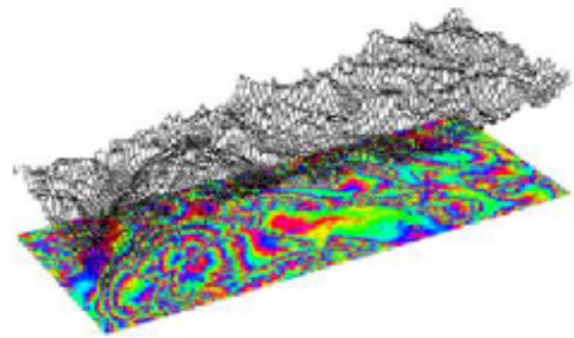
PolSAR:
sensitive to scat. mech.
influenced by
shape, orientation,
dielectric properties

InSAR:
$\Delta\phi$ → height and tomography
3D information

Textural prop.

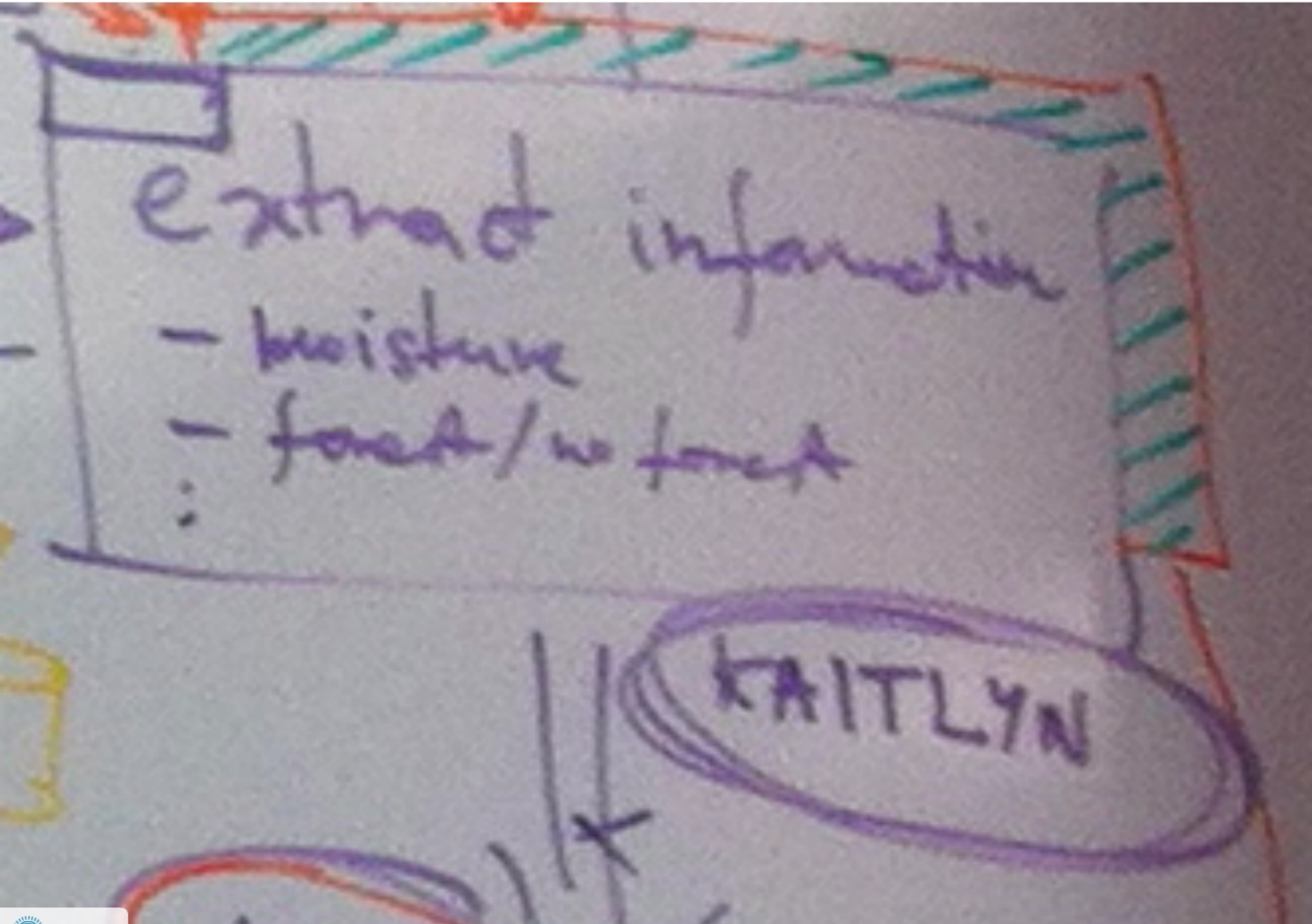
Spatial prop.

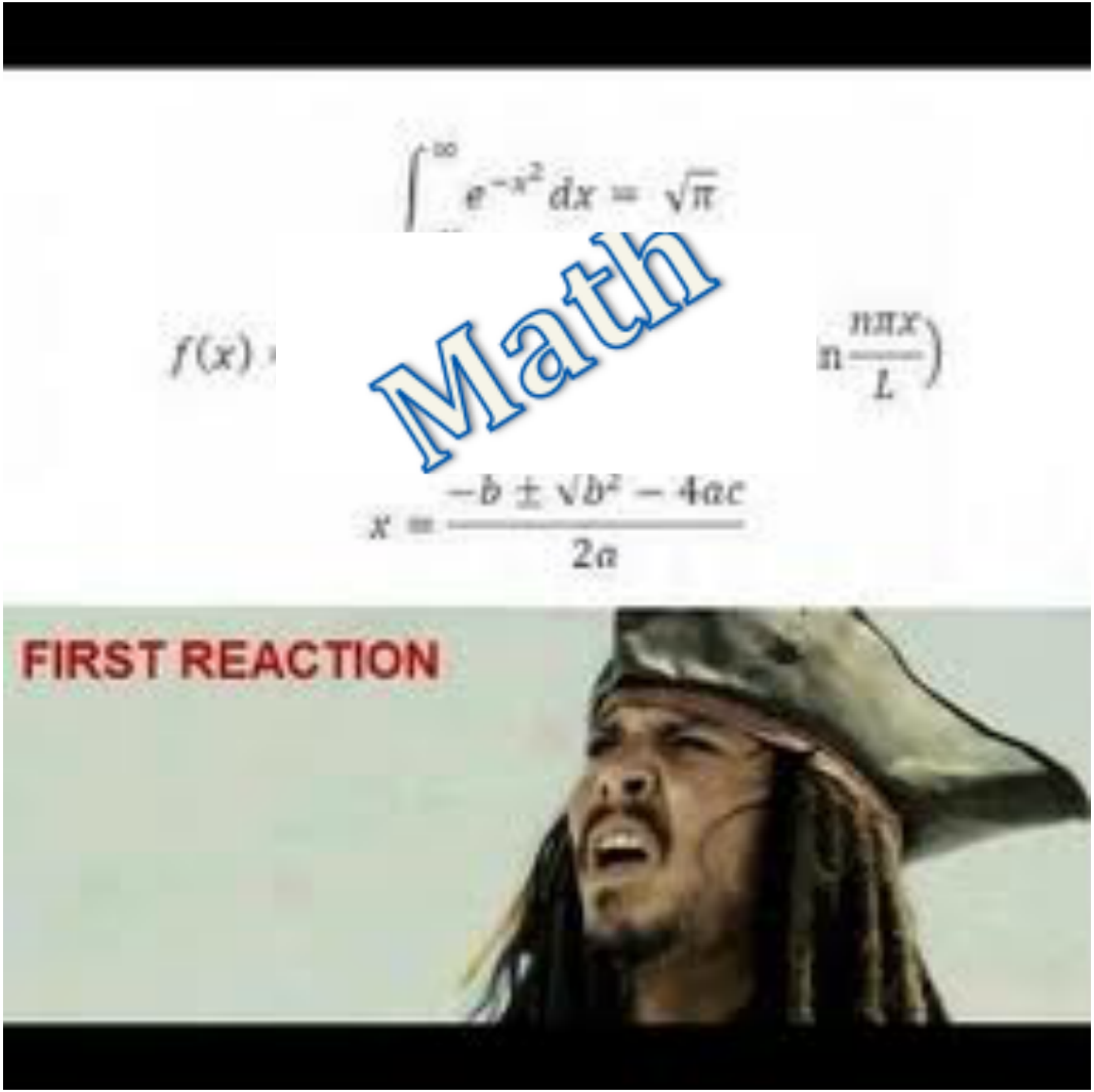




PolInSAR: computation of interferometric phases and coherences for different scattering mechanisms

Signal & Image Centre


extract information
- moisture
- force / no force
KAITLYN


$\int^{\infty} e^{-x^2} dx = \sqrt{\pi}$
Math
$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$
FIRST REACTION

to the Freeman–Durden model.

$$[T] = m_s \begin{bmatrix} \cos\alpha \\ -\sin\alpha \\ 0 \end{bmatrix} \cdot \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \end{bmatrix} + m_d \begin{bmatrix} \sin\alpha \\ \cos\alpha \\ 0 \end{bmatrix} \cdot \begin{bmatrix} \sin\alpha & \cos\alpha & 0 \end{bmatrix} + m_v \begin{bmatrix} F_p & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} m_s\cos^2\alpha + m_d\sin^2\alpha & \cos\alpha\sin\alpha(m_d - m_s) & 0 \\ \cos\alpha\sin\alpha(m_d - m_s) & m_d\cos^2\alpha + m_s\sin^2\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix} + \begin{bmatrix} F_p m_v & 0 & 0 \\ 0 & m_v & 0 \\ 0 & 0 & m_v \end{bmatrix}$$

HV

$$\Rightarrow [T]_{SD} = [T] - m_v \begin{bmatrix} F_p & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} m_s & 0 & 0 \\ 0 & m_d & 0 \\ 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (4.58)$$

v_1 v_2 V

is this the inverse of V? yes.

$$m_v = t_{33}$$

$$m_{d,s} = \frac{(t_{11} + t_{22} - (F_p + 1)t_{33}) \pm \sqrt{(t_{11} - t_{22} - (F_p - 1)t_{33})^2 + 4\,|t_{12}|^2}}{2}$$

$m_d \rightarrow -$

$m_s \rightarrow +$

$$\alpha_{max} = \cos^{-1}\left[\left(\sqrt{1 + \left|\frac{t_{12}}{t_{22} - t_{33} - m_{max}}\right|^2}\right)^{-\frac{1}{2}}\right]$$

Prezi

$$
\begin{aligned}
[T] = m_{\max} \begin{bmatrix} \cos\alpha_{\max} \\ -\sin\alpha_{\max} \\ 0 \end{bmatrix} \cdot \begin{bmatrix} \cos\alpha_{\max} & -\sin\alpha_{\max} & 0 \end{bmatrix} \\
+ m_{\min} \begin{bmatrix} \sin\alpha_{\max} \\ \cos\alpha_{\max} \\ 0 \end{bmatrix} \cdot \begin{bmatrix} \sin\alpha_{\max} & \cos\alpha_{\max} & 0 \end{bmatrix} \\
+ m_v \begin{bmatrix} F_p & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}
\end{aligned}
$$

$$
\underline{w} = \begin{bmatrix} \cos\alpha_{\max} \\ \sin\alpha_{\max} \\ 0 \end{bmatrix} \Rightarrow \underline{w}^{*T}\left([T]\right)\underline{w} = m_{\max} + m_v\left(1 + (F_p - 1)\cos^2\alpha_{\max}\right)
$$

$$
\Rightarrow \mu = \frac{surface}{volume} = \frac{m_{\max}}{m_v}\,\frac{1}{\left(1 + (F_p - 1)\cos^2\alpha_{\max}\right)} \tag{4.61}
$$

component (either m_s or m_d), then we can obtain a direct estimate of the maximum surface-to-volume ratio by finding the largest eigenvalue of $[T_V]^{-1}[T_{\max}]$, as shown in equation (4.62):

$$
\begin{aligned}
\frac{m_{\max}}{m_v}\begin{vmatrix} \dfrac{\cos^2\alpha_{\max}}{F_p} - \mu & \dfrac{\cos\alpha_{\max}\sin\alpha_{\max}}{F_p} \\ \cos\alpha_{\max}\sin\alpha_{\max} & \sin^2\alpha_{\max} - \mu \end{vmatrix} = 0 \\
\Rightarrow \mu_{\max} = \frac{m_{\max}}{m_v}\left(\sin^2\alpha_{\max} + \frac{1}{F_p}\cos^2\alpha_{\max}\right)
\end{aligned} \tag{4.62}
$$

The MATH!

Proofs of Cloude's Formulas

Kaitlyn Fiechtner

August 6, 2012

$$[T] = m_s \begin{bmatrix} cos\alpha \\ -sin\alpha \\ 0 \end{bmatrix} \cdot \begin{bmatrix} cos\alpha & -sin\alpha & 0 \end{bmatrix} +$$

$$\begin{bmatrix} m_s \cos^2 \alpha_{min} + m_d \sin^2 \alpha_{min} & \cos \alpha_{min} \sin \alpha_{min}(m_d - m_s) \\ \sin \alpha_{min} \cos \alpha_{min} & m_d \cos^2 \alpha + m_s \sin^2 \alpha \end{bmatrix} \cdot cos(\alpha_{min})$$

$$[T] = \begin{bmatrix} cos\alpha & sin\alpha & 0 \\ -sin\alpha & cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} m_s & 0 & 0 \\ 0 & m_d & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} cos\alpha & -sin\alpha & 0 \\ sin\alpha & cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Now,

$$\text{LetV} = \begin{bmatrix} cos\alpha & sin\alpha & 0 \\ -sin\alpha & cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

and let

$$D = \begin{bmatrix} m_s & 0 & 0 \\ 0 & m_d & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

We have shown that

$$VDV^{-1} = [T]$$

Now, we must show that

$$V^{-1}$$

is in fact the inverse of V.

$$V = \begin{bmatrix} cos\alpha & sin\alpha & 0 \\ -sin\alpha & cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

We will use matrix blocks to show

$$V^{-1}$$

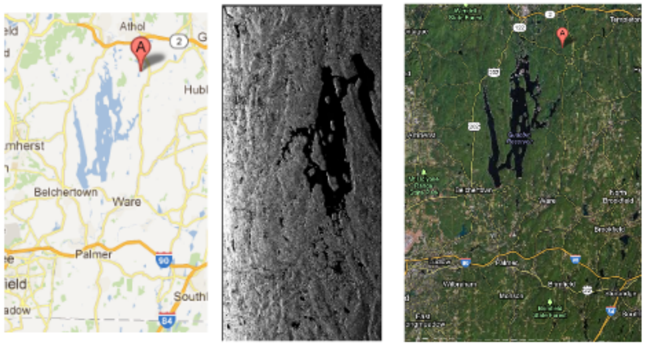
is in fact the inverse of V.

Inverting a Matrix Using Blocks

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}^{-1} = \begin{bmatrix} A^{-1} + B(D - CA^{-1}B)^{-1}CA^{-1} & -A^{-1}B(D - CA^{-1}B)^{-1} \\ -(D - CA^{-1}B)^{-1} & (D - CA^{-1}B)^{-1} \end{bmatrix}$$

$$A = \begin{bmatrix} cos\alpha & sin\alpha & 0 \\ -sin\alpha & cos\alpha & 0 \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad C = \begin{bmatrix} 0 & 0 \end{bmatrix} \quad D = \begin{bmatrix} 1 \end{bmatrix}$$

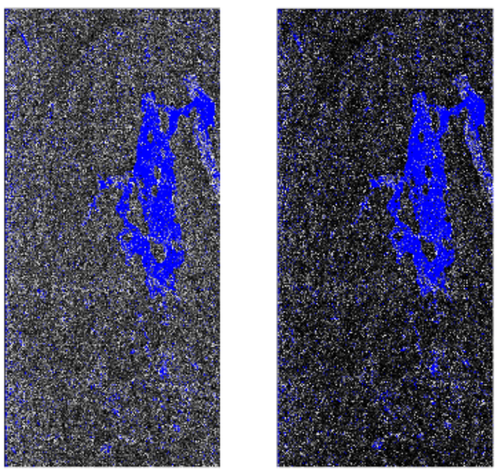
Harvard Forest MA



http://makeagif.com/i/RDQjfF
http://makeagif.com/i/pLkW9f
http://makeagif.com/i/pLkW9f

Masks

0 to 1 | 0 to 2

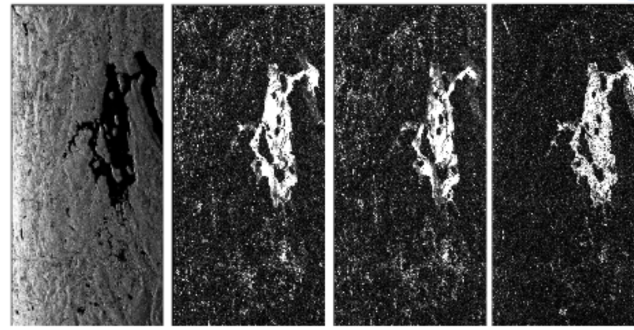


.1 — 5
Darker=volume/lighter=surface
Darker = less change

- Masked Data

Harvard Forest Images, MA

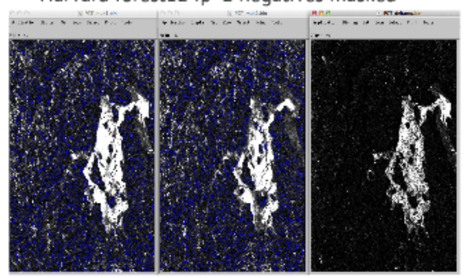
T11 | muk1 | muk2 | deltamu



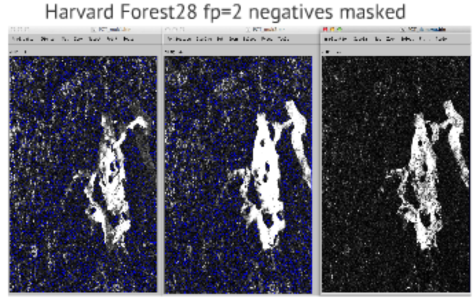
muk = surface/volume

.1 — 5
Darker=volume/lighter=surface
Darker = less change

Harvard forest12 fp=2 negatives masked



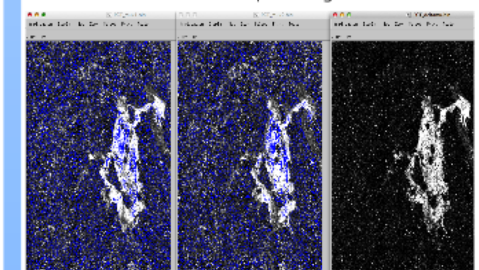
Harvard Forest28 fp=2 negatives masked



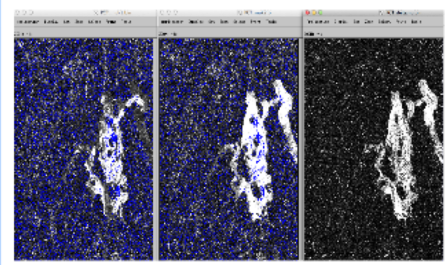
.1 — 5
Lighter=surface/Darker=volume
Darker = less change

- Masked Data

Harvard Forest Fp!=2 negatives masked



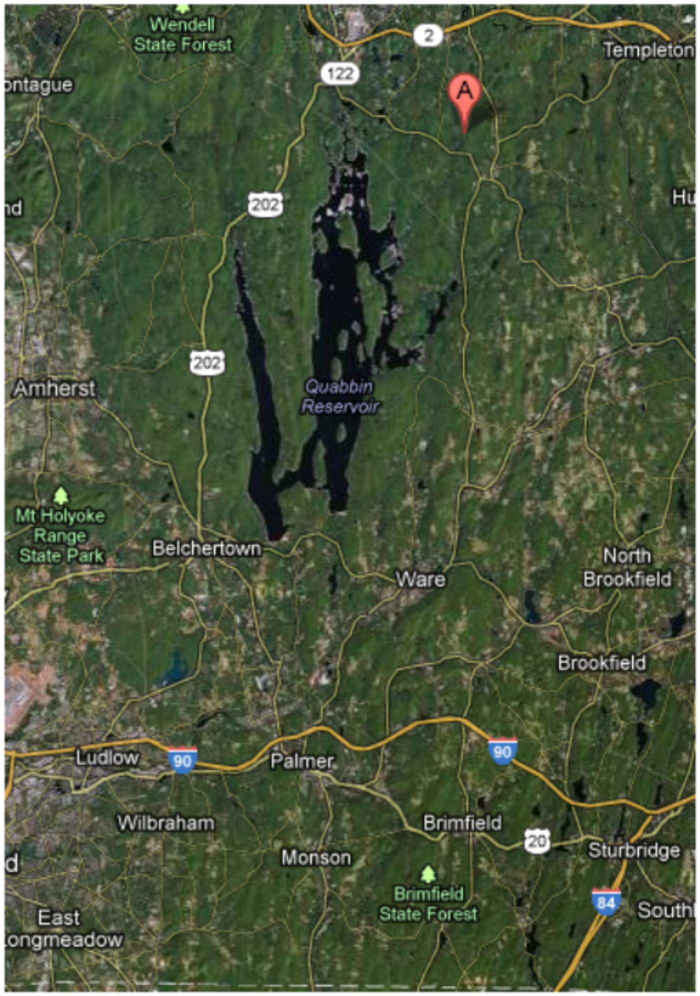
Harvard Forest28 fp!=2 negatives masked



.1 — 5
Darker=volume/lighter=surface
Darker = less change

- Masked Data

Harvard Forest MA

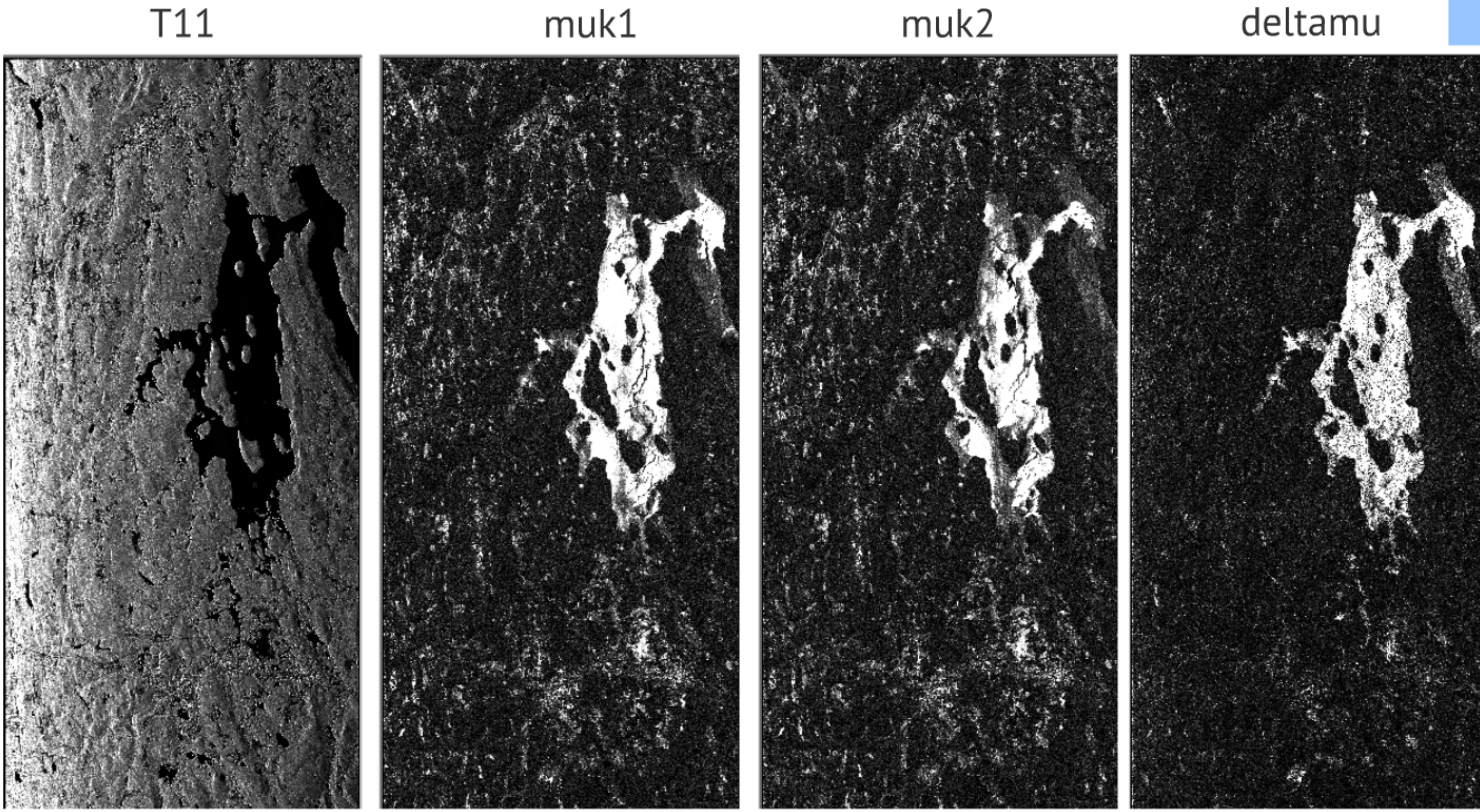


http://makeagif.com/i/RDQjfF

http://makeagif.com/i/pLkW9f

http://makeagif.com/i/pLkW9f

Harvard Forest Images, MA



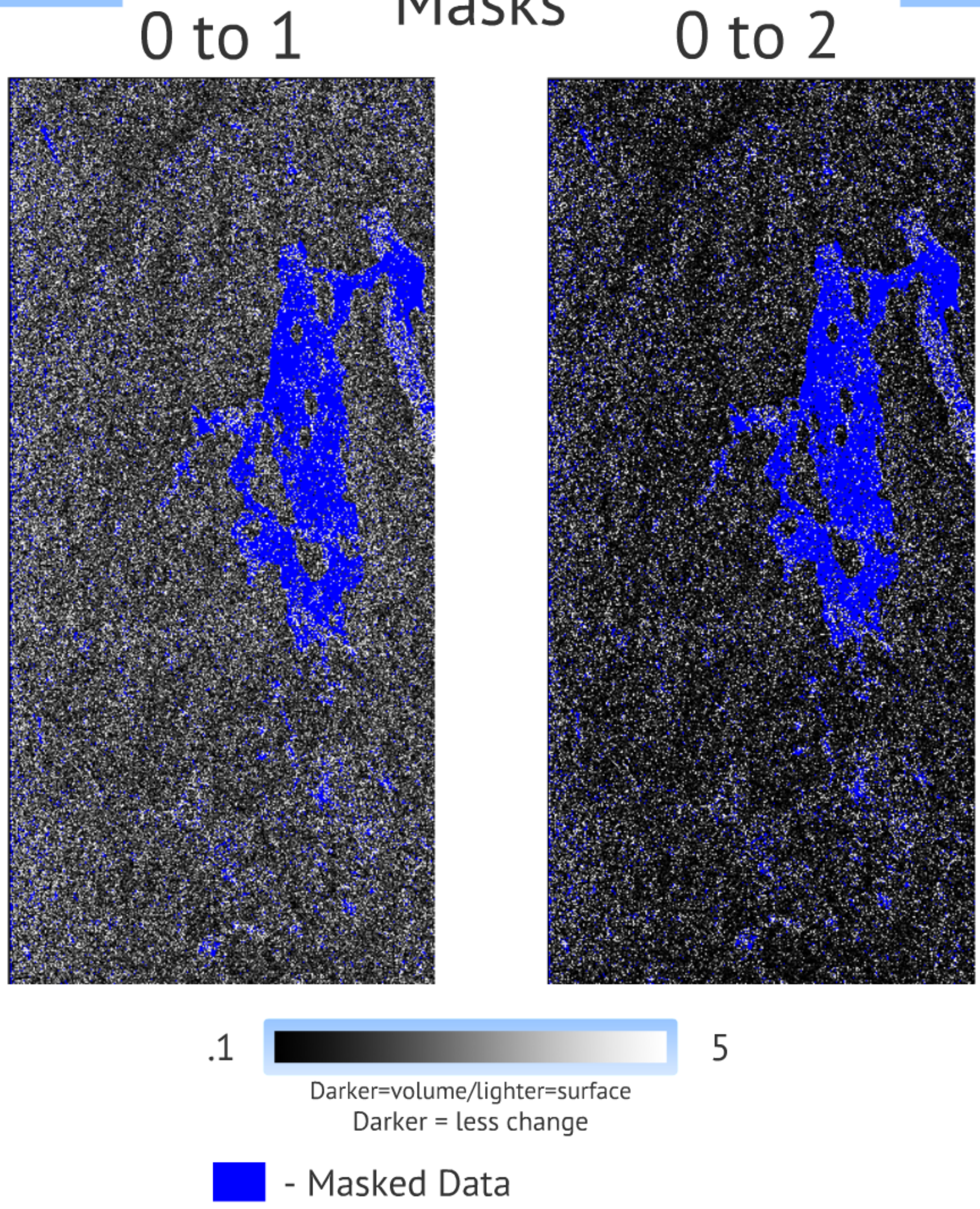
muk = surface/volume

Darker=volume/lighter=surface

Darker = less change


WHEN IN ROME!
ICANHASCHEEZBURGER.COM

Masks


0 to 1
0 to 2
.1
5
Darker=volume/lighter=surface
Darker = less change
- Masked Data

Prezi

QjfF

W9f

W9f

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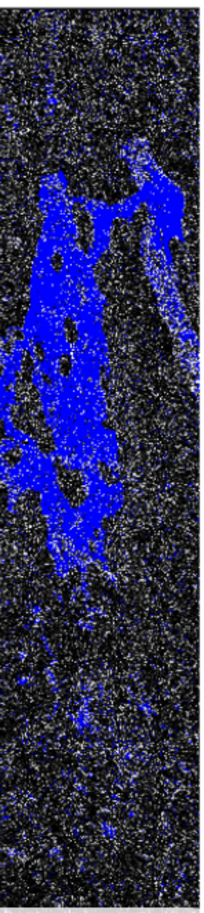
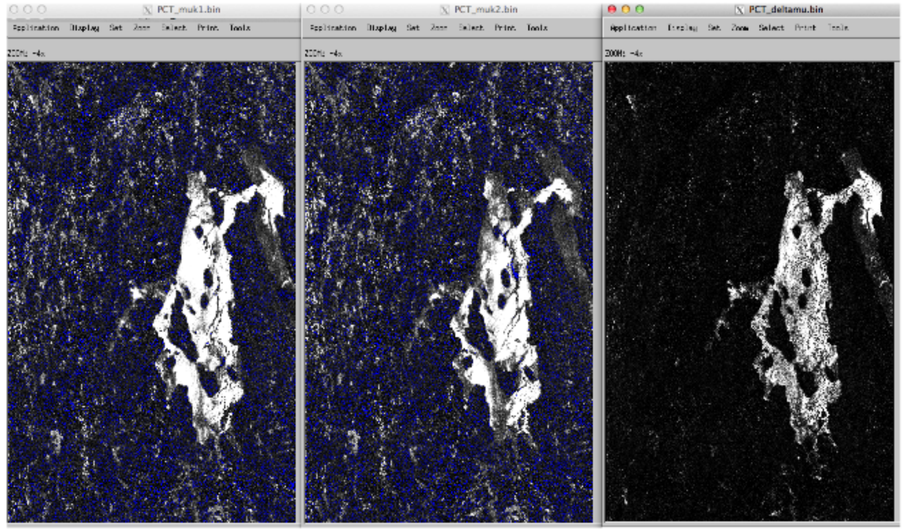


Harvard forest12 fp=2 negatives masked



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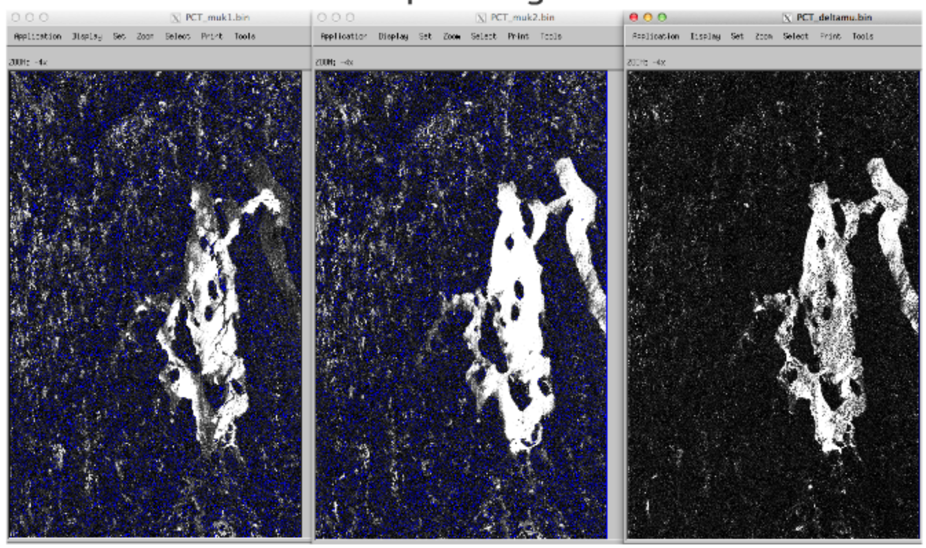
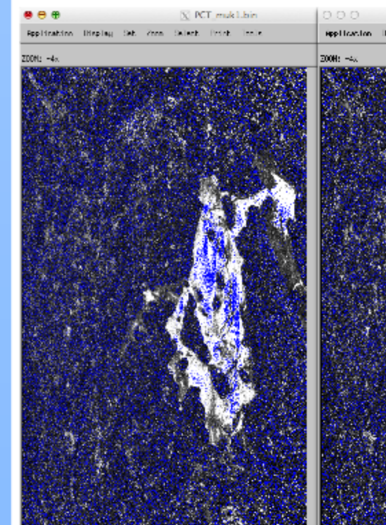


Lighter=surface/Darker=volume

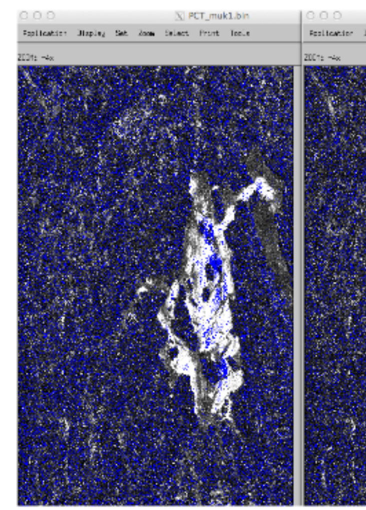
Darker = less change

- Masked Data

Harvard For



Harvard For



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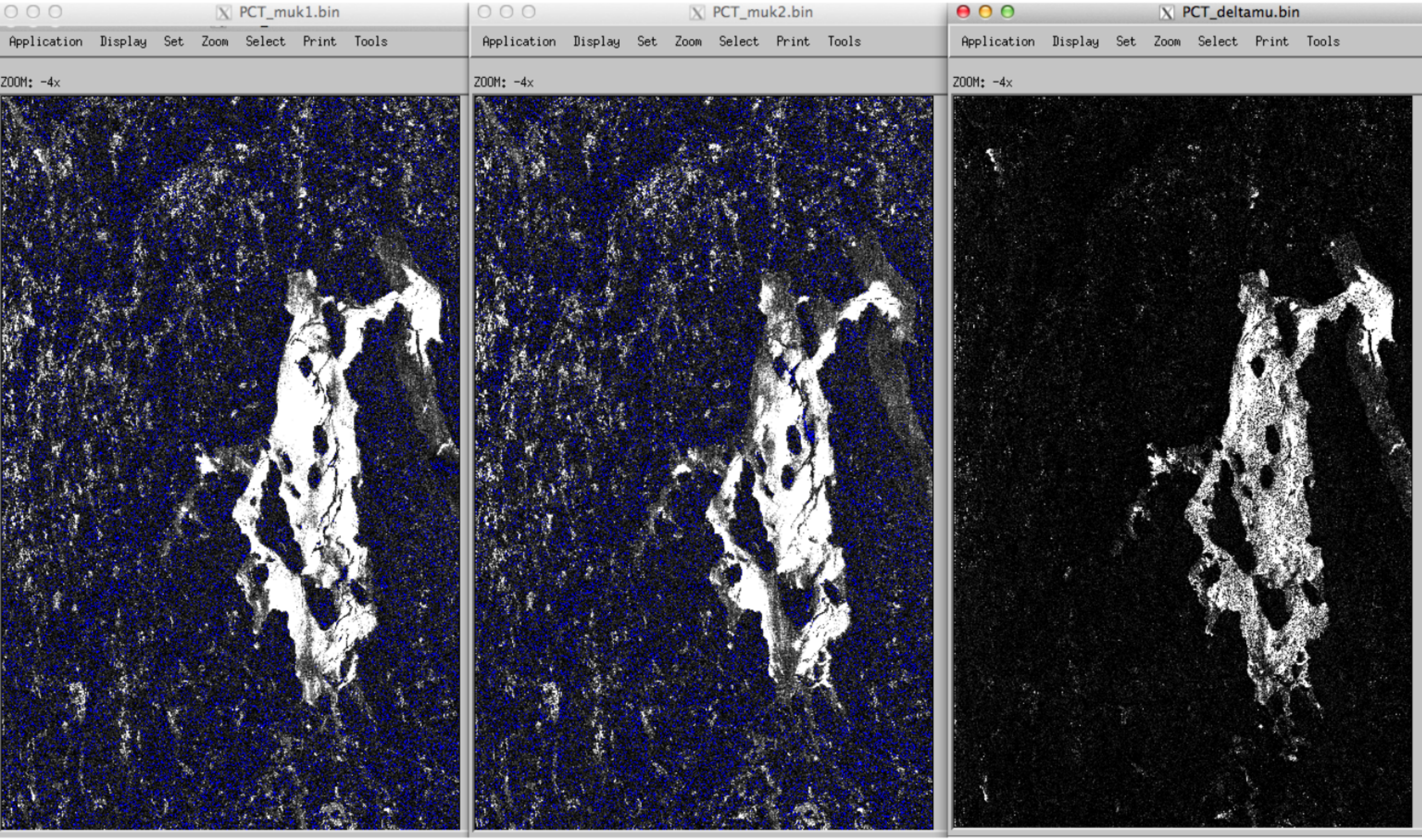
Harvard forest12 fp=2 negatives masked



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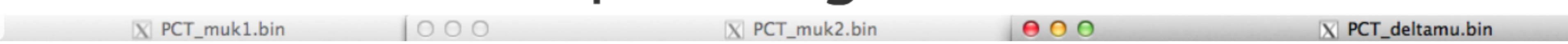
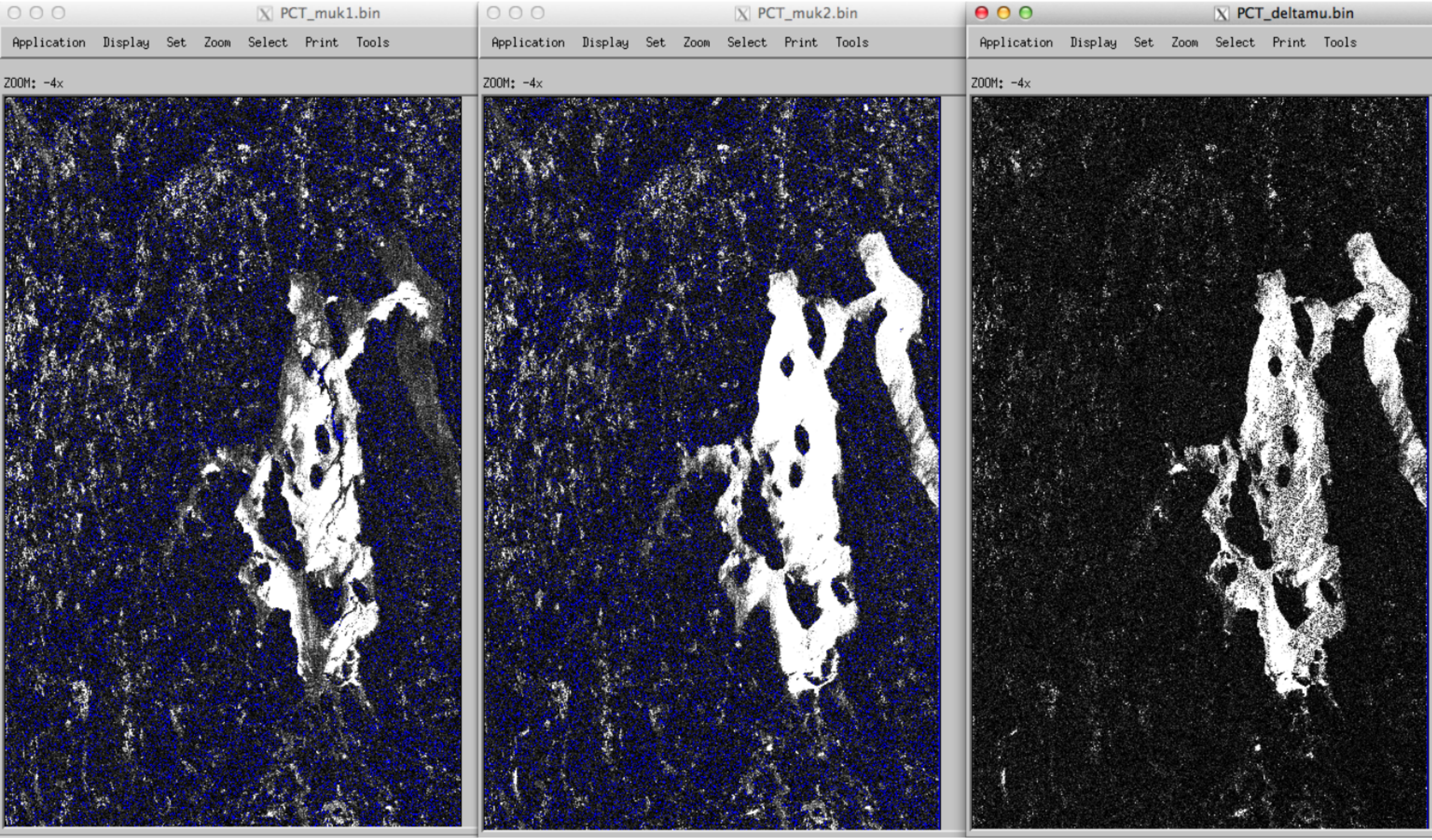
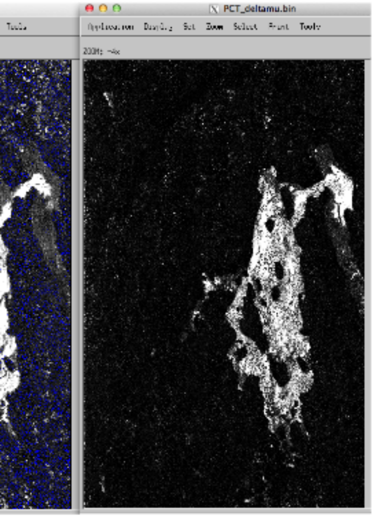


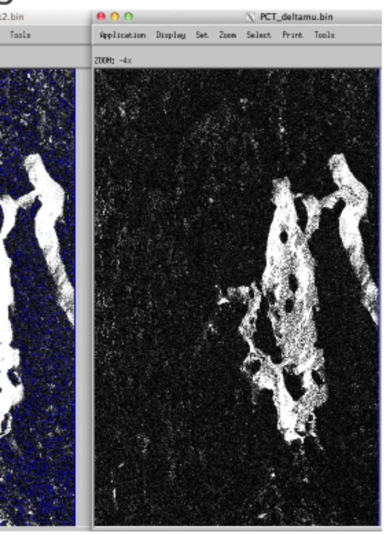
Harvard Forest28 fp=2 negatives masked



gatives masked



gatives masked



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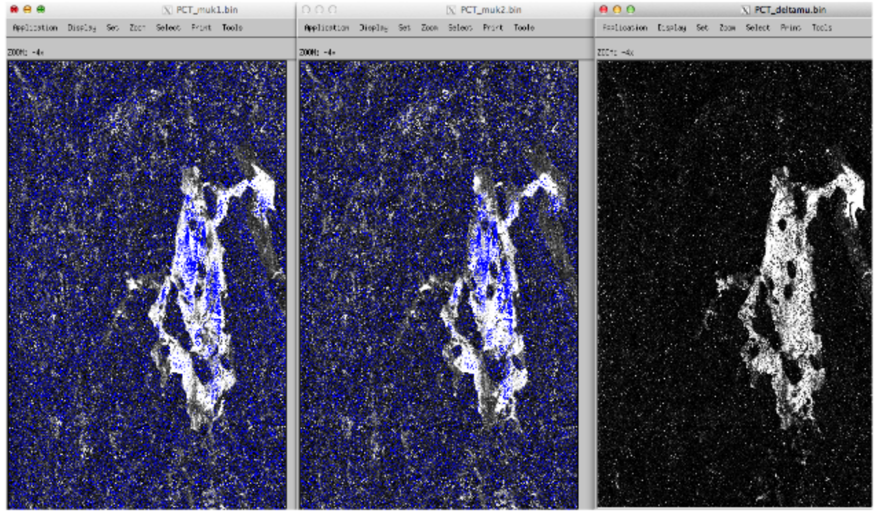
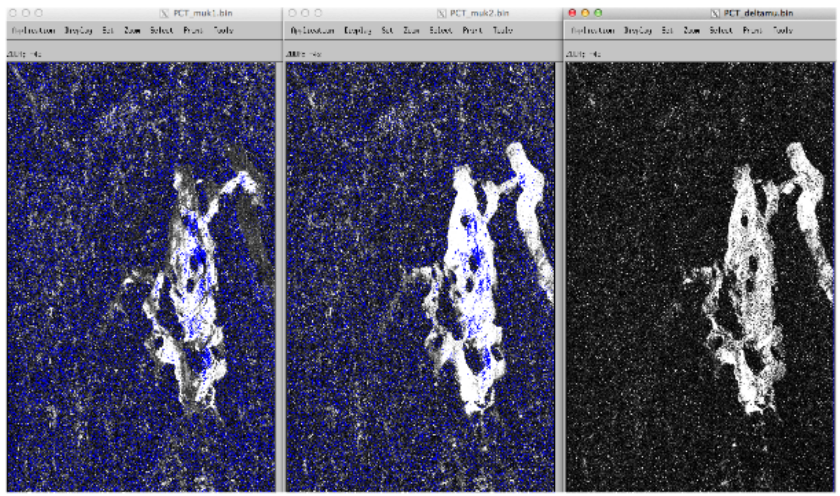
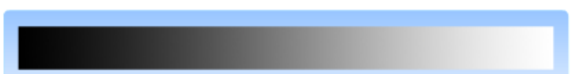
Harvard Forest Fp!=2 negatives masked



Harvard Forest28 fp!=2 negatives masked

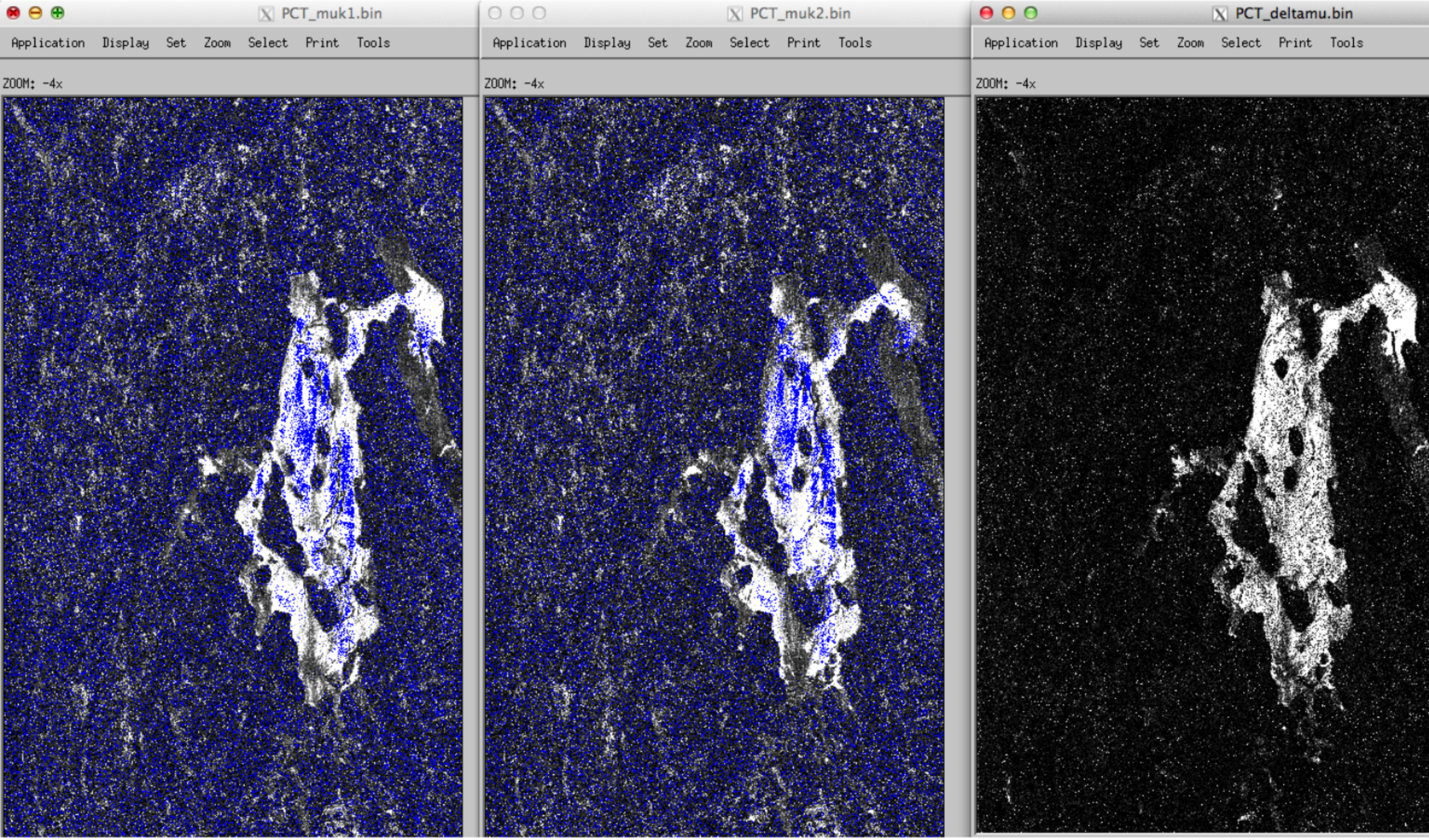


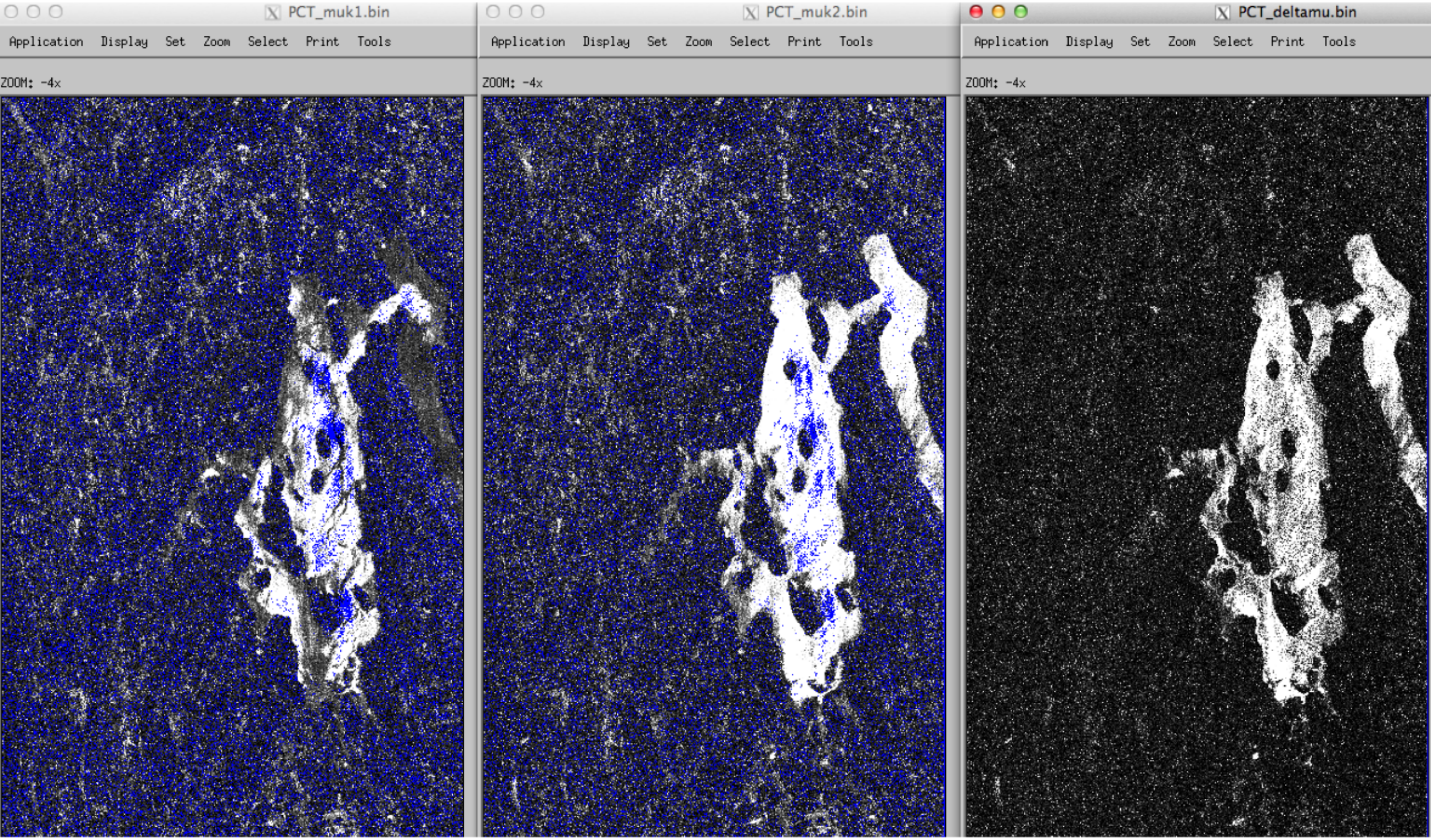
.1  5

Darker=volume/lighter=surface
Darker = less change

- Masked Data

Harvard Forest Fp!=2 negatives masked



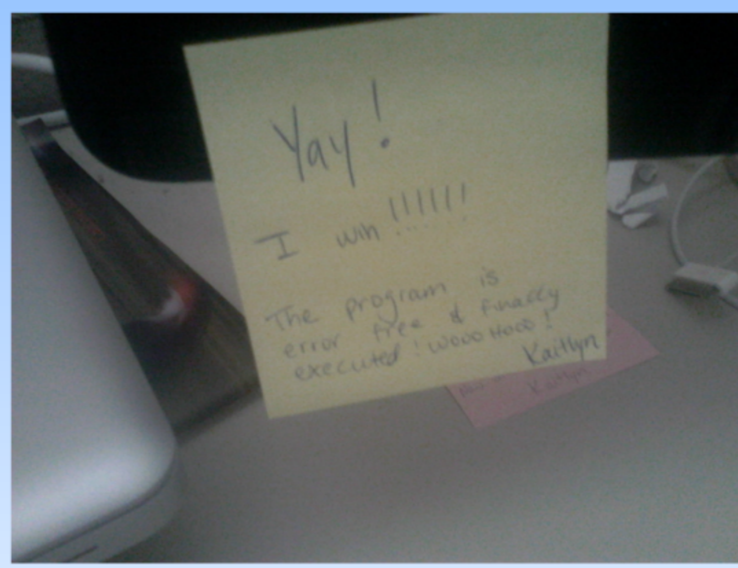

PCT_muk1.bin
Application Display Set Zoom Select Print Tools
ZOOM: -4x
PCT_muk2.bin
Application Display Set Zoom Select Print Tools
ZOOM: -4x
PCT_deltamu.bin
Application Display Set Zoom Select Print Tools
ZOOM: -4x

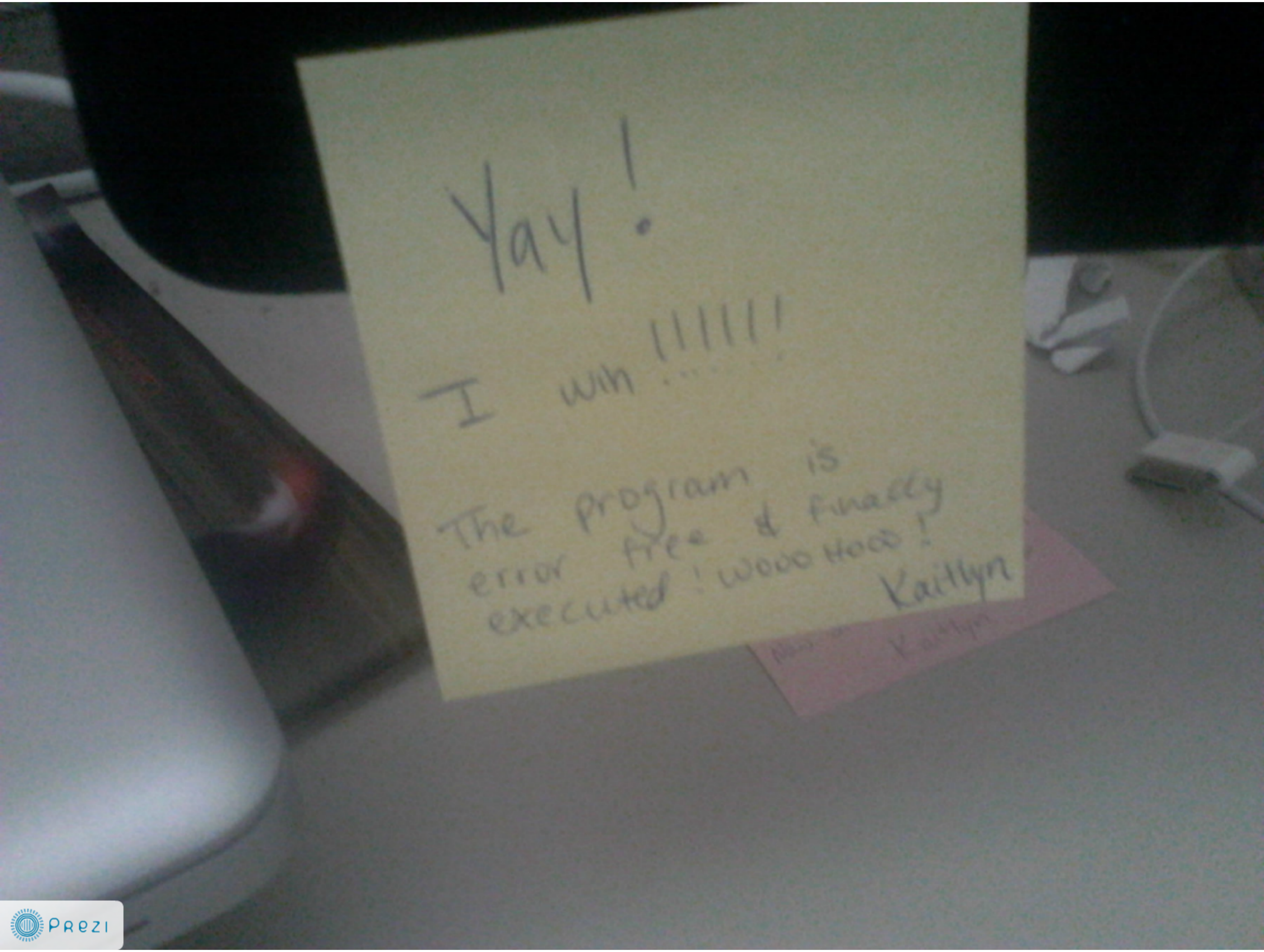
$$\left[\left(\sqrt{1+\left|\frac{t_{12}}{t_{22}-t_{33}-m_{\max}}\right|^{2}}\right)^{-\frac{1}{2}}\right]$$

Compiler Errors

```
albenson-1570929:~ fiechtne$ gcc -g -Wall lib/graphics.c lib/matrix.c lib/proces
sing.c  lib/util.c lib/test/main.c  -o ./PCT_prepare_T6_dumpmore5coh.exe -lm -We
xtra
lib/util.c:212: warning: unused parameter 'file'
lib/test/main.c:83:30: error: /lib/test/matrix.h: No such file or directory
lib/test/main.c:84:28: error: lib/processing.h: No such file or directory
lib/test/main.c:85:25: error: ../lib/util.h: No such file or directory
```

```
albenson-1570929:~ fiechtne$ gcc -g -Wall lib/graphics.c lib/matrix.c lib/proces
sing.c  lib/util.c lib/test/main.c  -o ./PCT_prepare_T6_dumpmore5coh.exe -lm -We
xtra
lib/util.c:212: warning: unused parameter 'file'
lib/test/main.c: In function 'main':
```

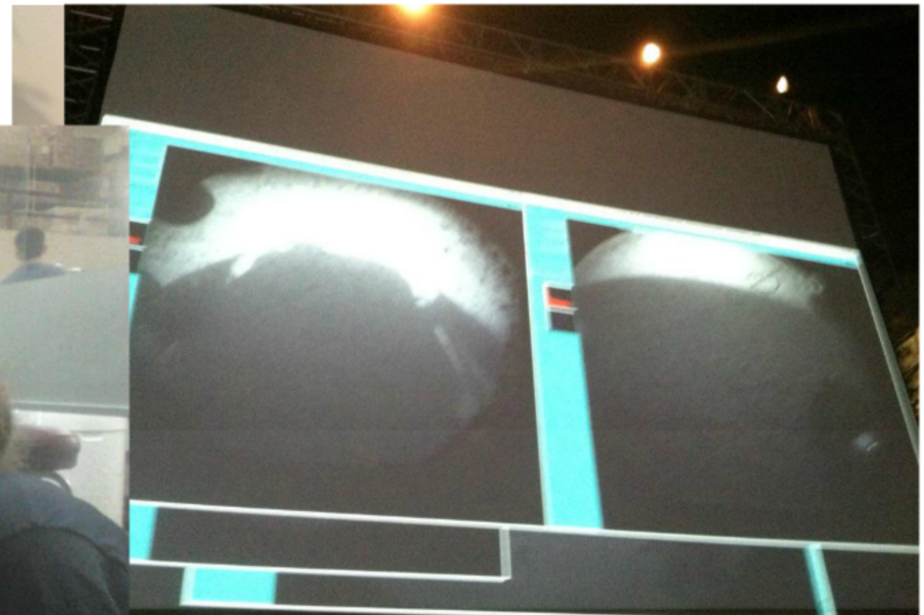



Yay!
I win!!!!!!
The program is error free & finally executed! WOOO HOO!
Kaitlyn

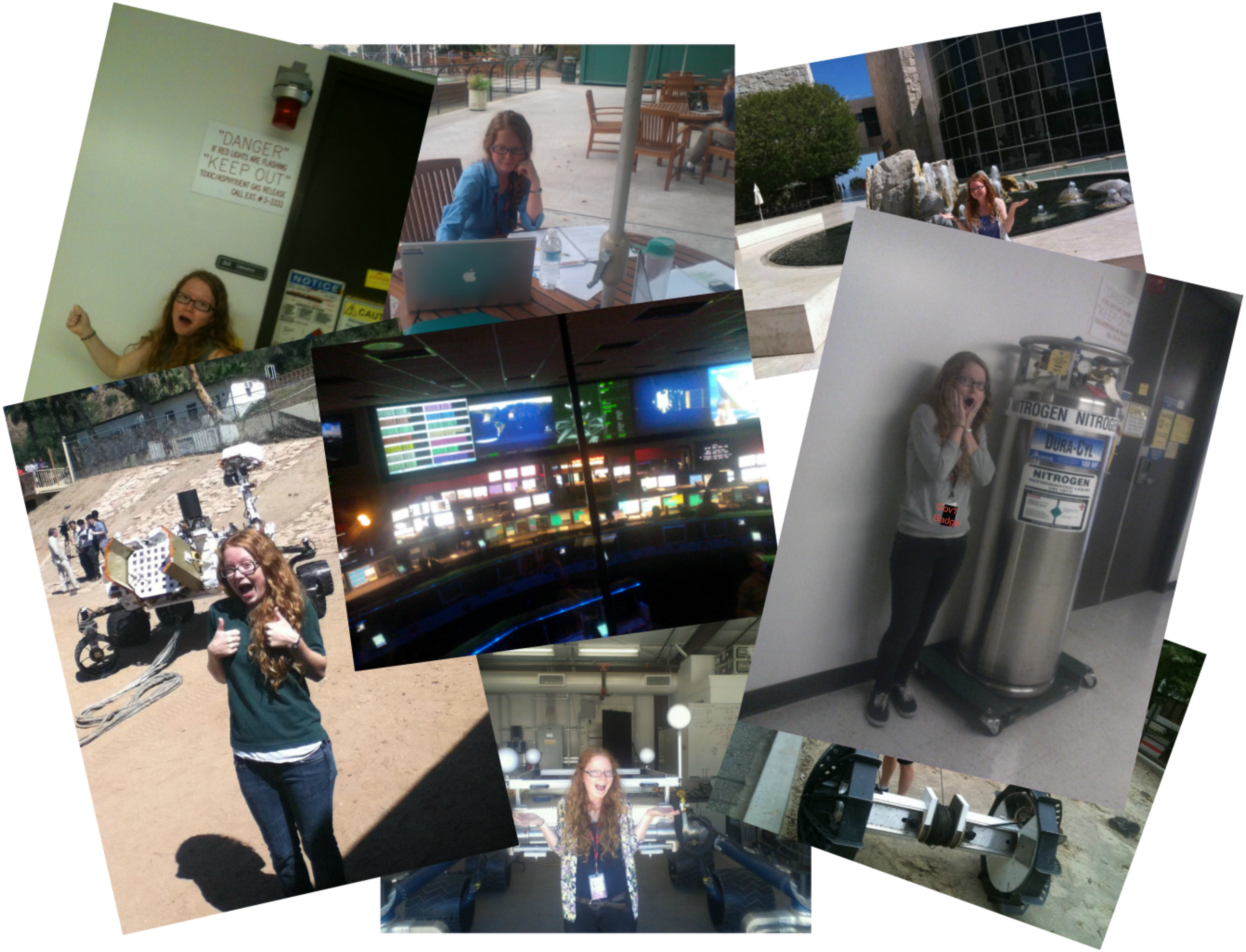
References

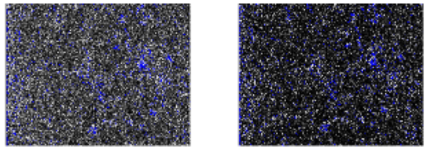
- Cloude, S.R. (2010). Polarisation applications in remote sensing. Oxford, NY: Oxford University Press.
- Lavalle, Marco and Hensley, Scott. Demonstration of Repeat-Pass Polinsar Using UAVSAR: The RMOG Model.
- Lavalle, M., Simard, M., & Hensley, S. (n.d.). A Temporal Decorrelation Model for Polarimetric Radar Interferometers. Ieee Transactions on Geoscience and Remote Sensing.
- Acheroy, Marc. Fusion of optical and PolInSAR data for land cover classification. 2007. ppt.
- JPL UAVSAR Overview ppt. http://uavsar.jpl.nasa.gov/overview.html
- http://en.wikipedia.org/wiki/Invertible_matrix

This material is based upon work supported by the S.D. Bechtel, Jr. Foundation and by the National Science Foundation under Grant No. 0952013 and Grant No. 0934931 (East Bay Noyce Fellows only) and Grant No. 0833353 (check funding spreadsheet if needed). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the S.D. Bechtel, Jr. Foundation or the National Science Foundation. This project has also been made possible with support of the National Marine Sanctuary Foundation.
The STAR program is administered by the Cal Poly Center for Excellence in Science and Mathematics Education (CESaME) on behalf of the California State University (CSU)

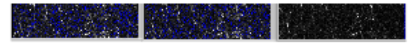



carmela
ice cream & sorbet
1 scoop $3.50
2 scoops $4.50
SALTED CARAMEL
BROWN SUGAR VANILLA BEAN
FRESH MINT w/ CACAO NIBS
LAVENDER HONEY
STRAWBERRY BUTTERMILK
INTELLIGENTSIA ESPRESSO
LEMON VERBENA VANILLA BEAN
SORBET

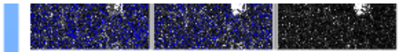

"DANGER"
IF RED LIGHTS ARE FLASHING
"KEEP OUT"
NOTICE
NITROGEN NITROGEN
DURA-CYL
NITROGEN



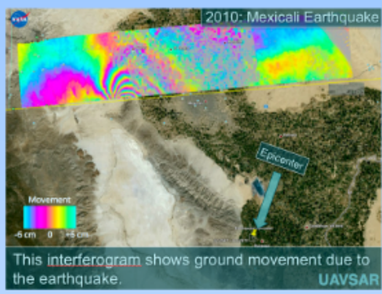
.1 5
Darker=volume/lighter=surface
Darker = less change
- Masked Data

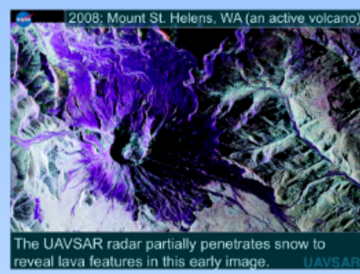


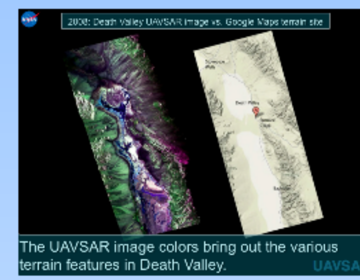
.1 5
Lighter=surface/Darker=volume
Darker = less change
- Masked Data

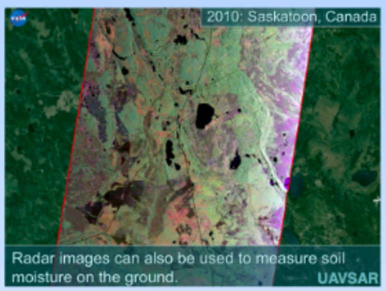


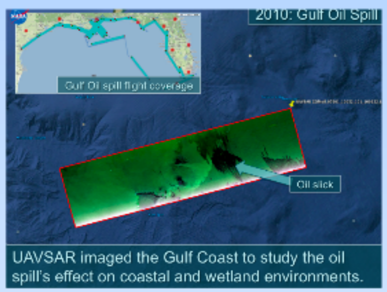
.1 5
Darker=volume/lighter=surface
Darker = less change
- Masked Data

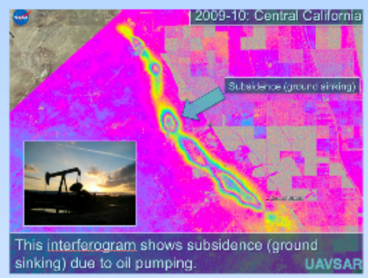


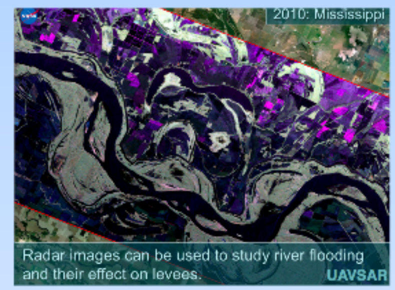


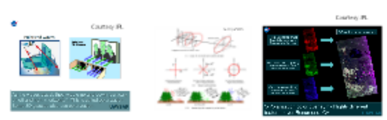




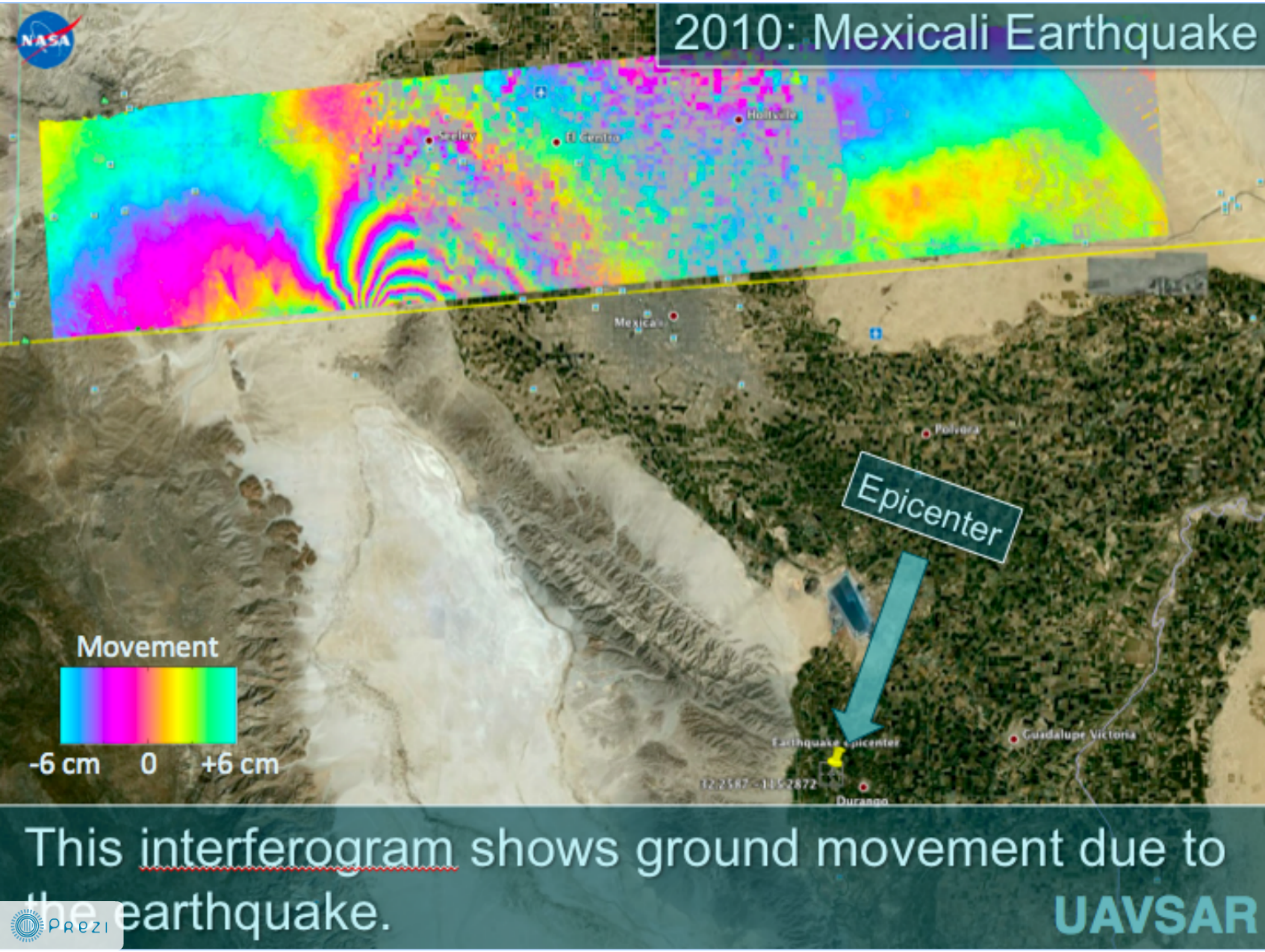






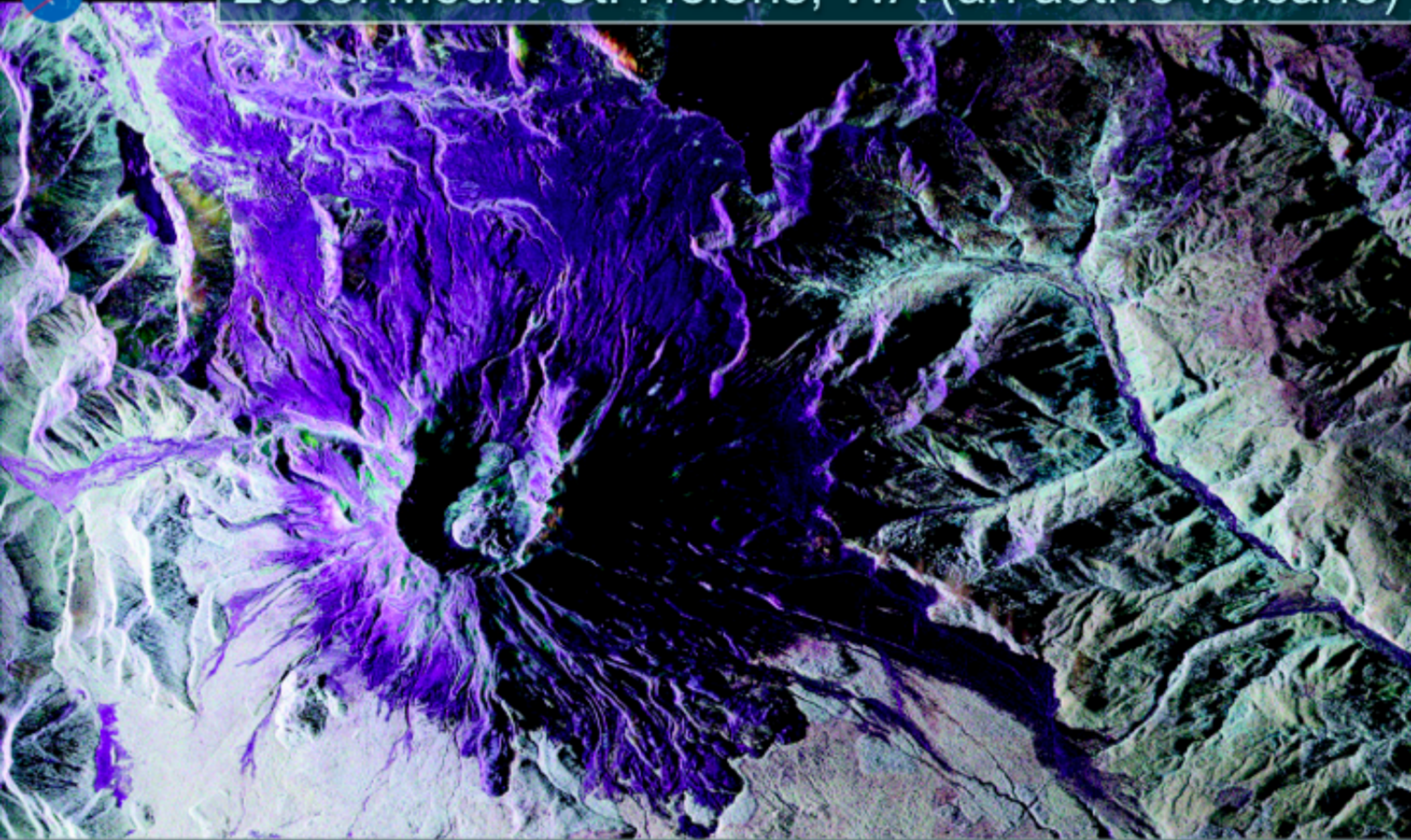


2010: Mexicali Earthquake



This interferogram shows ground movement due to the earthquake.

2008: Mount St. Helens, WA (an active volcano)

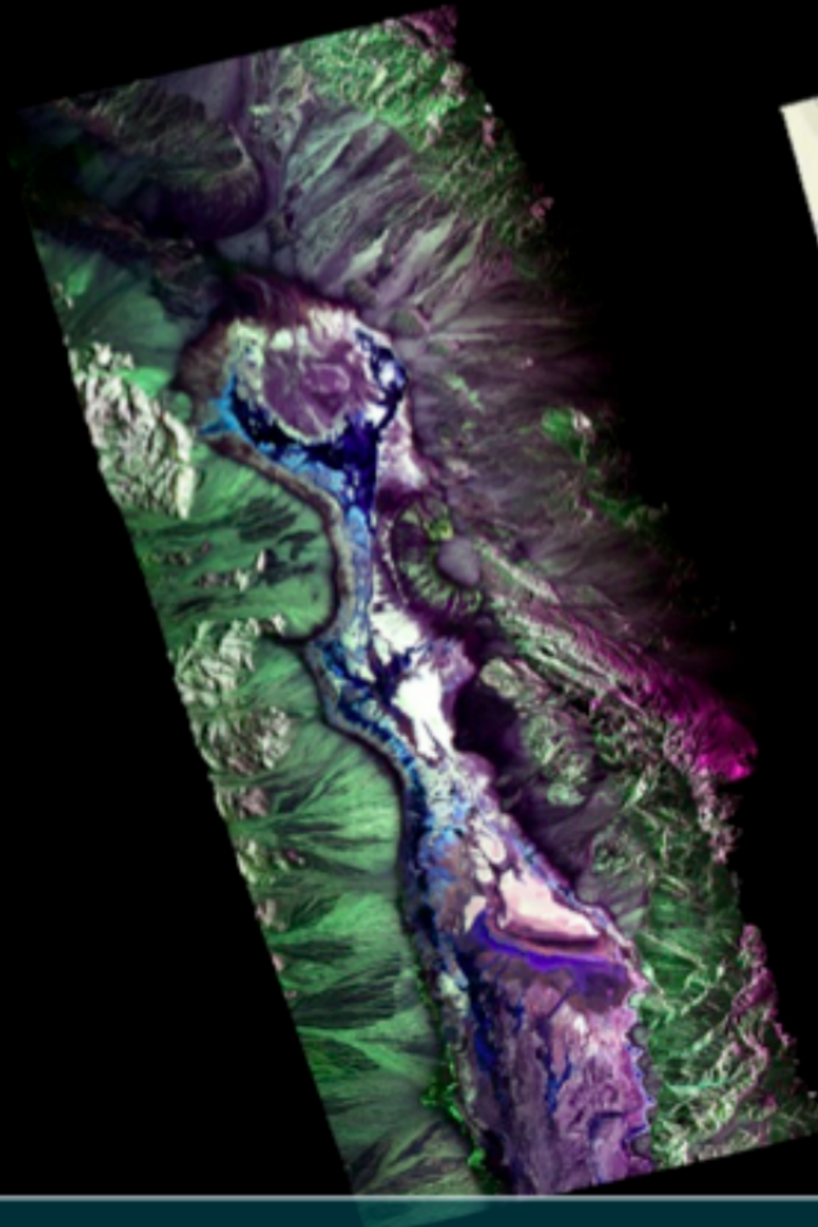


The UAVSAR radar partially penetrates snow to reveal lava features in this early image.

UAVSAR

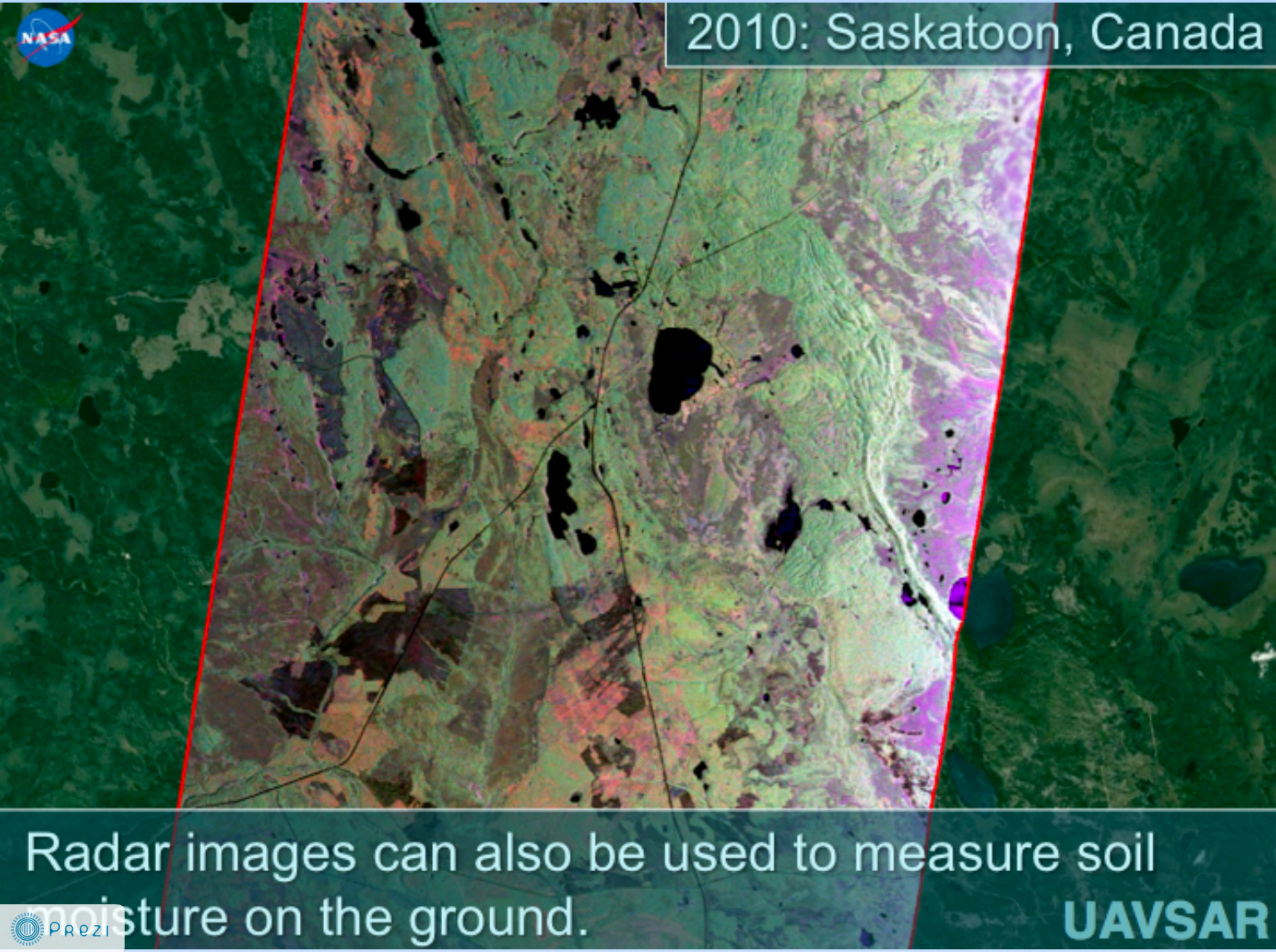
UAVSAR image: Kangerlugssuaq Ice Fjord
Photo: Sonderstrom Glacier
This 2009 Greenland radar image shows glacier flow.
UAVSAR

2008: Death Valley UAVSAR image vs. Google Maps terrain site

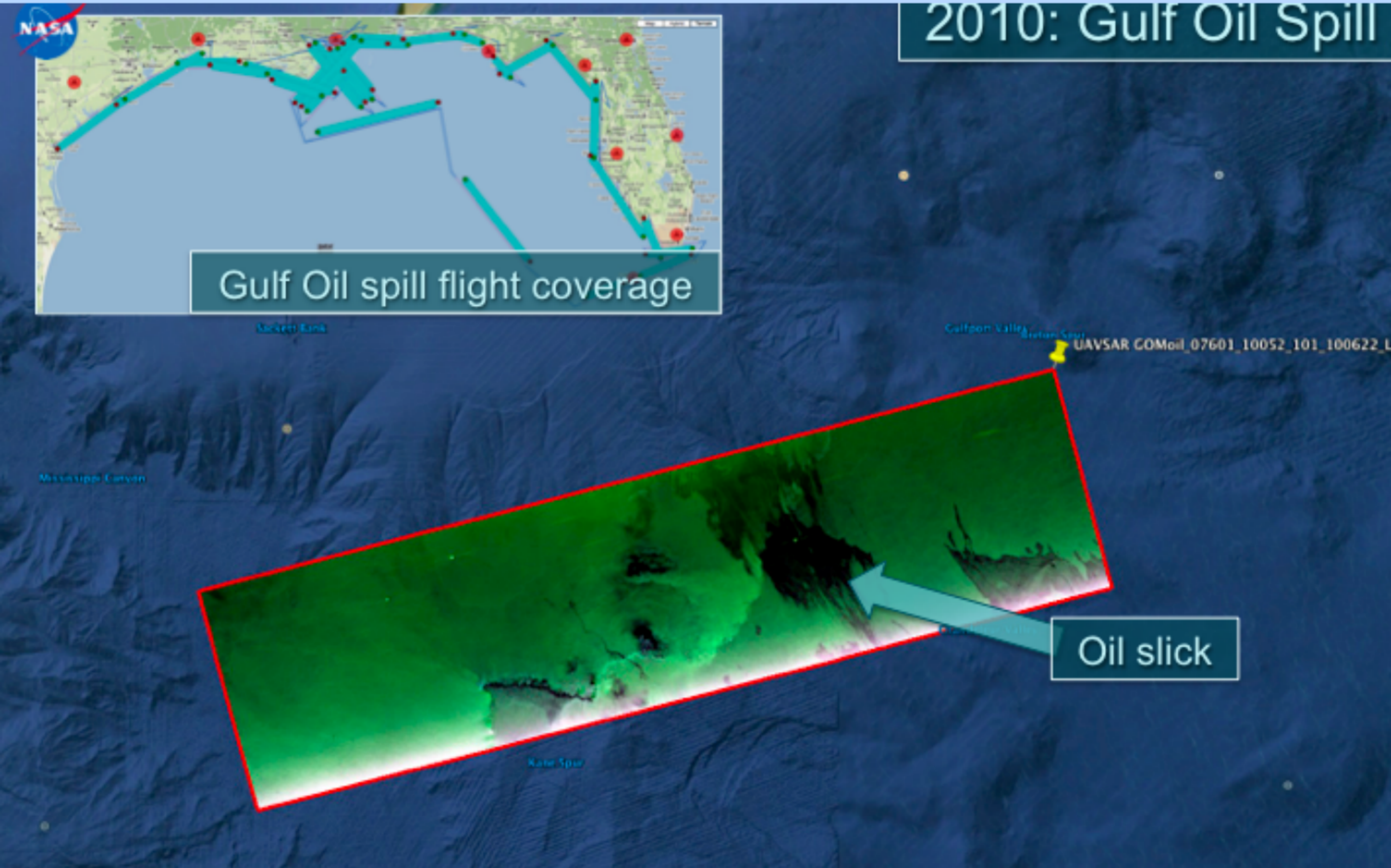


The UAVSAR image colors bring out the various terrain features in Death Valley.

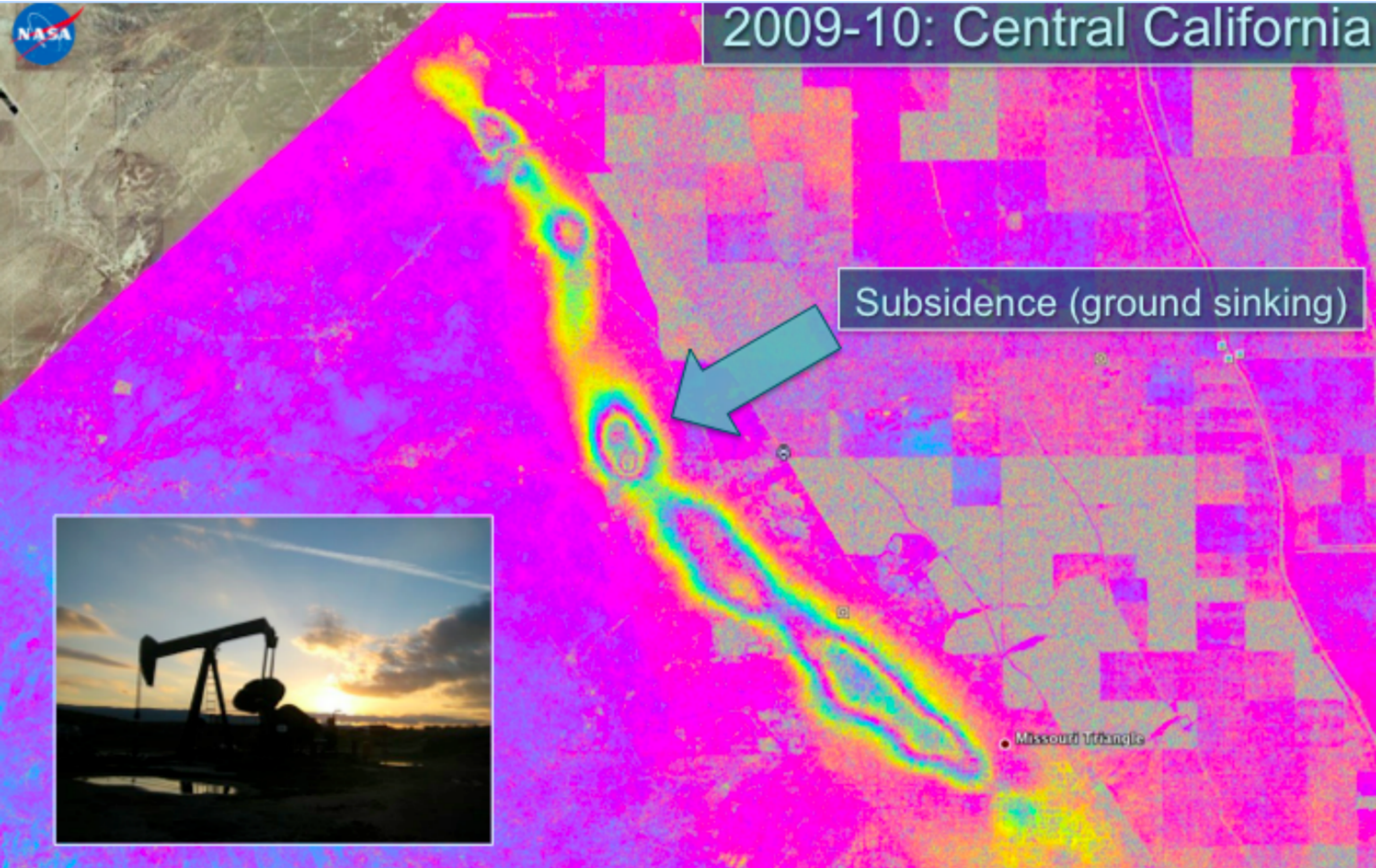
UAVSAR


2010: Saskatoon, Canada
Radar images can also be used to measure soil moisture on the ground.
UAVSAR

2010: Gulf Oil Spill

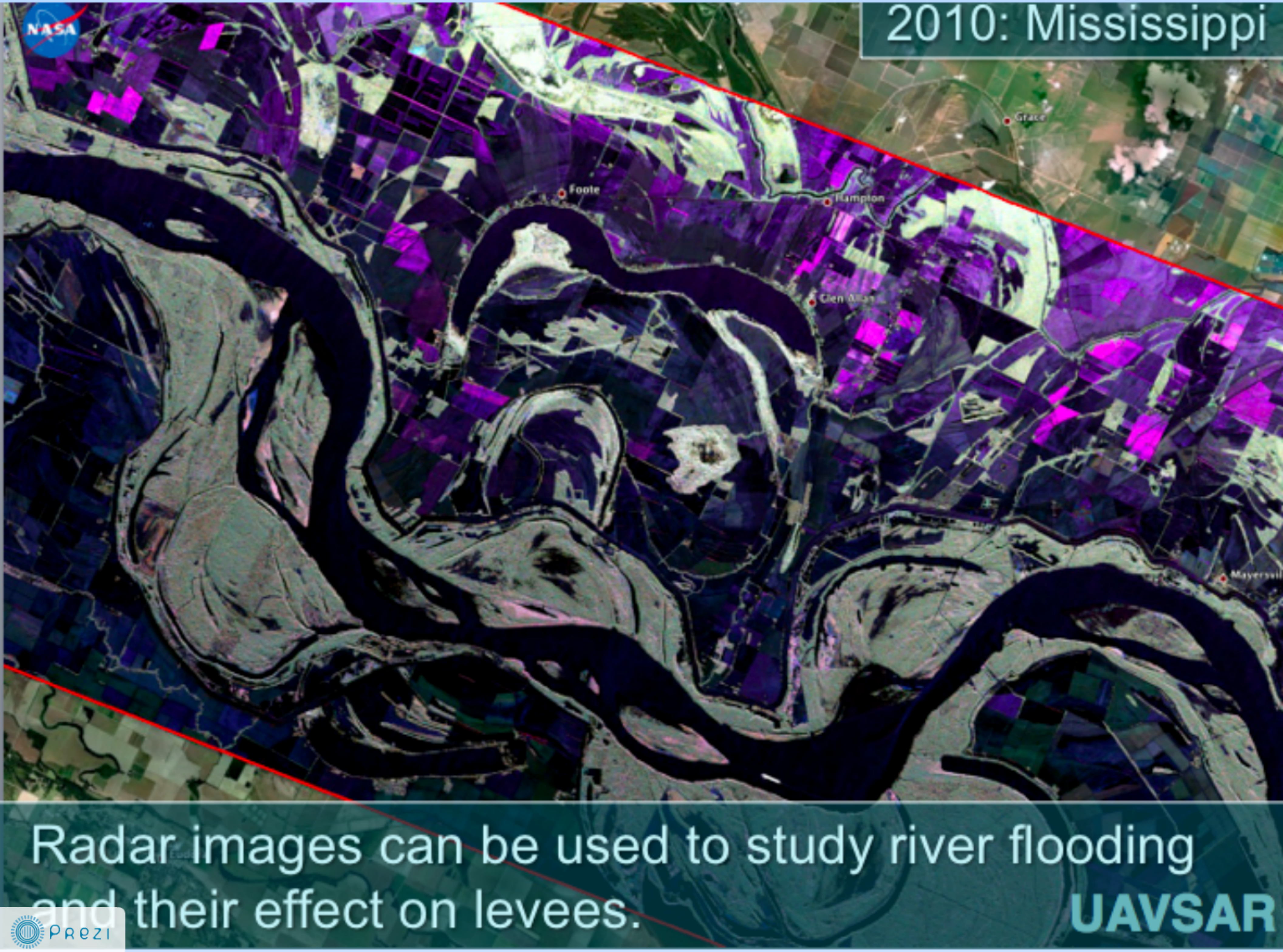


UAVSAR imaged the Gulf Coast to study the oil spill's effect on coastal and wetland environments.



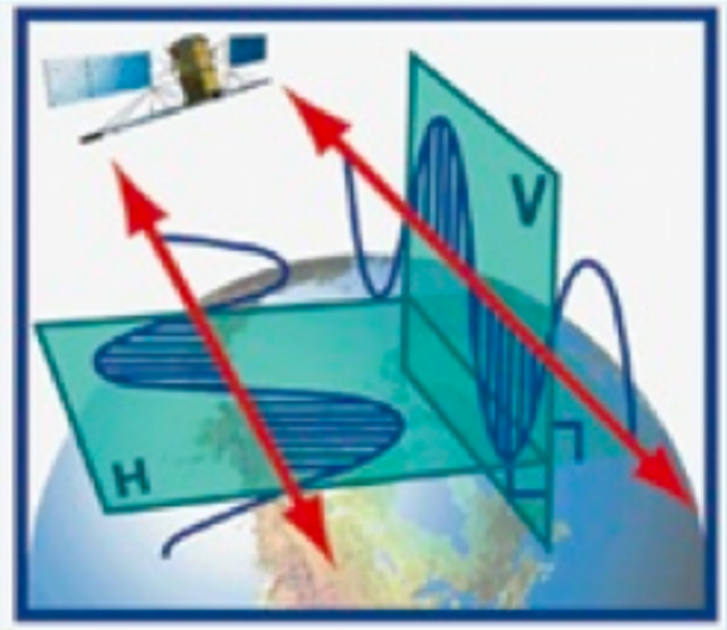
This interferogram shows subsidence (ground sinking) due to oil pumping.

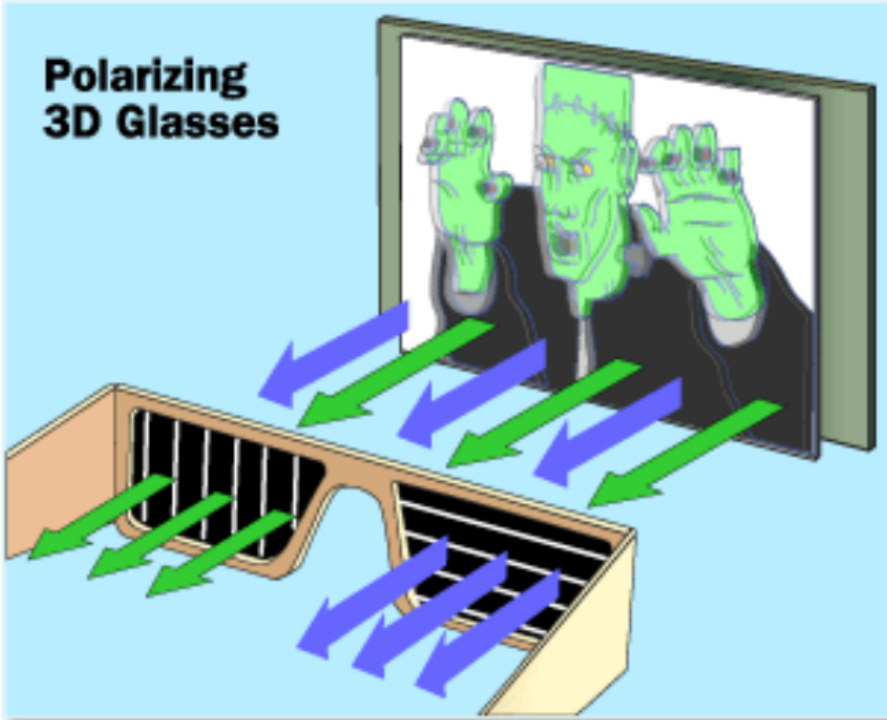
UAVSAR


NASA
2010: Mississippi
Grace
Foote
Hampton
Glen Allan
Radar images can be used to study river flooding and their effect on levees.
UAVSAR

Courtesy JPL

Polarized waves

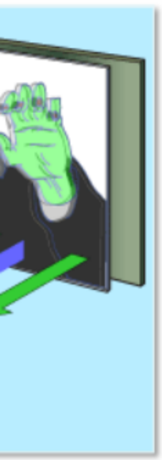




As the waves travel, they wiggle up and down (vertical), or left and right (horizontal). This is called polarization. Some 3D glasses also use polarization.

UAVSAR

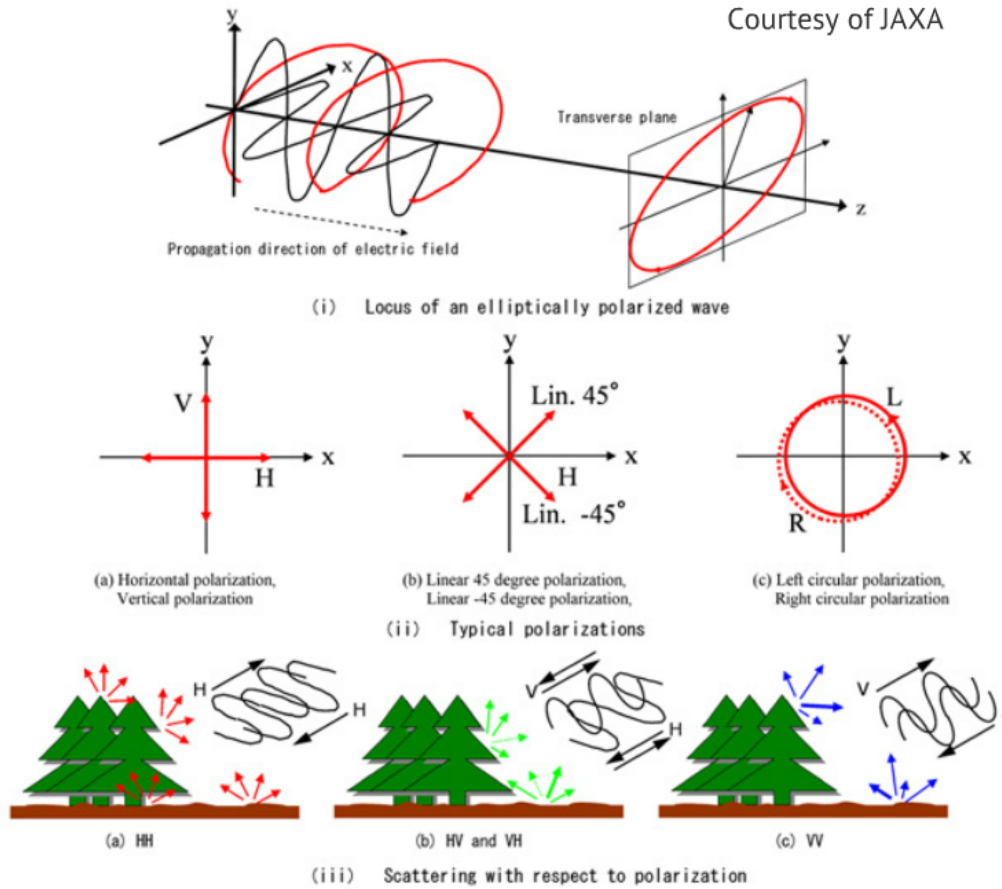
esy JPL



n (vertical),
arization.

UAVSAR

Courtesy of JAXA



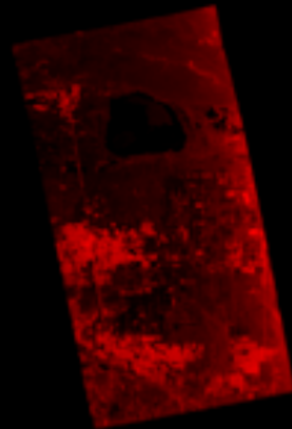
HH polarization (red)
Transmits horizontal waves
Receives horizontal waves

HV polarization (green)
Transmits horizontal waves
Receives vertical waves

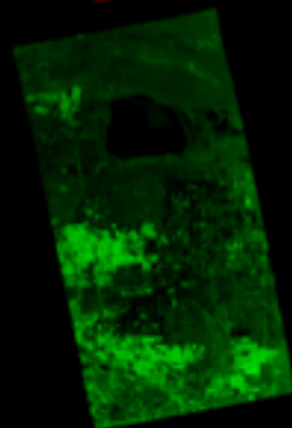
VV polarization (blue)
Transmits vertical waves
Receives vertical waves

3-Polarization c
features over R

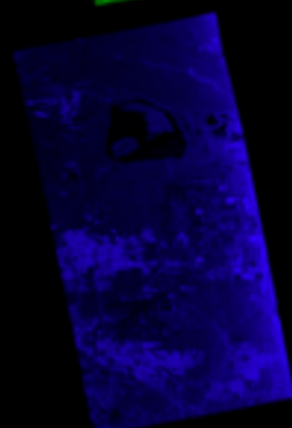
HH polarization (red)
Transmits horizontal waves
Receives horizontal waves



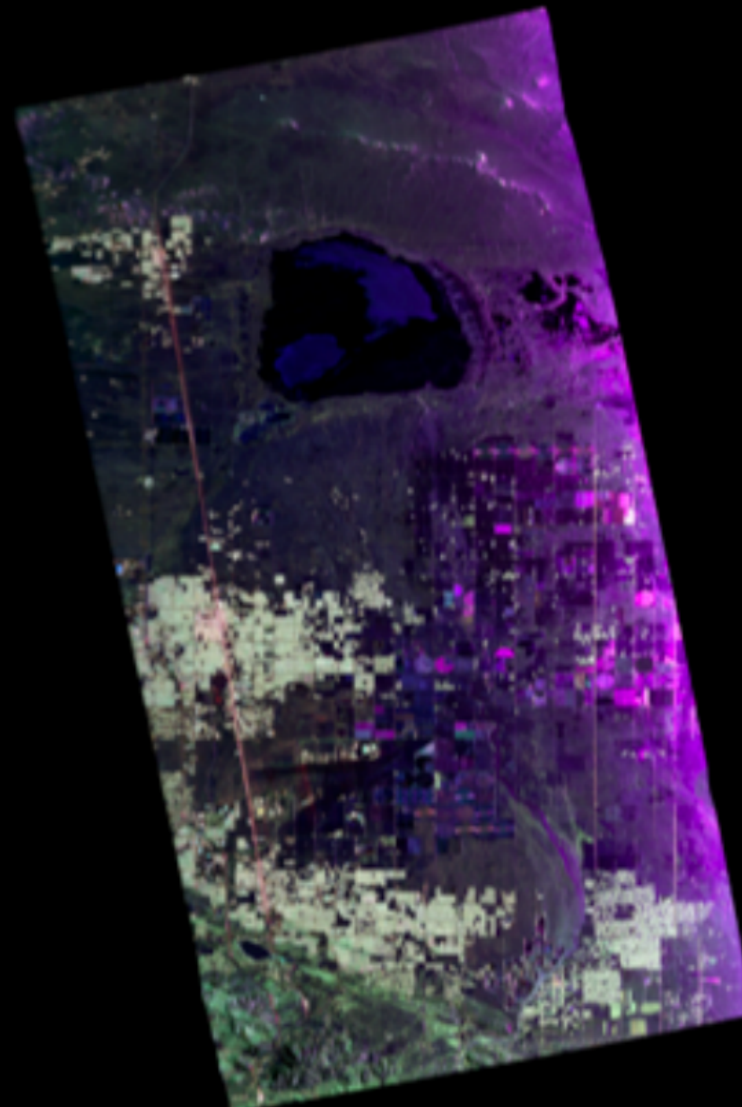
HV polarization (green)
Transmits horizontal waves
Receives vertical waves



VV polarization (blue)
Transmits vertical waves
Receives vertical waves



3-Polarization color overlay



3-Polarization color overlay highlights different features over Rosamond, CA

UAVSAR