

Quality Assessment of Shuttle Radar Topography Mission C- and X-Band Interferometric Data:

Implications for the Retrieval of Vegetation Canopy Height

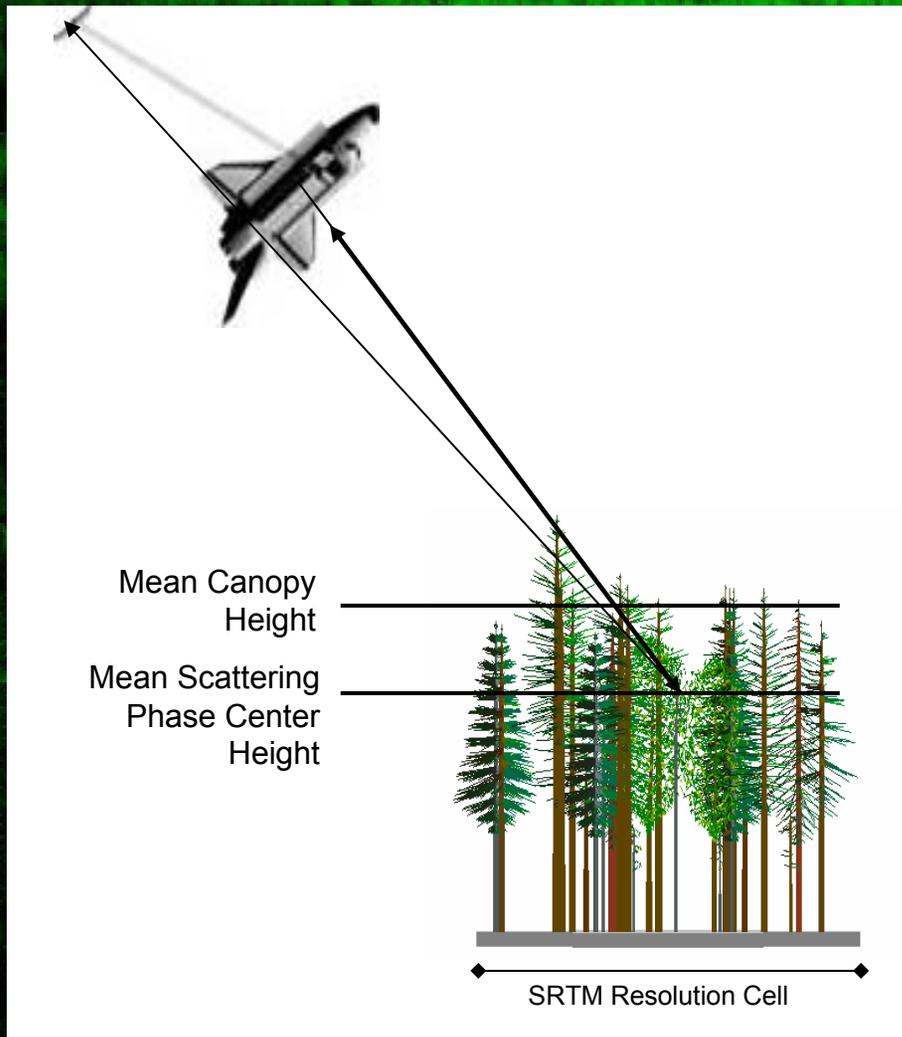
Wayne Walker^{1,2}
Josef Kellndorfer²
Leland Pierce¹

E-mail: josefk@whrc.org

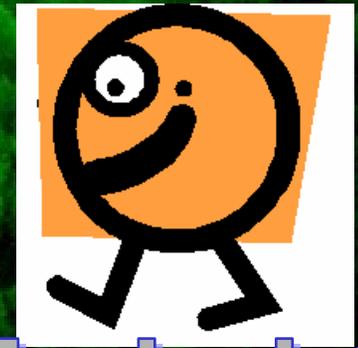
1 Radiation Laboratory, The University of Michigan
2 The Woods Hole Research Center



SRTM Vegetation Response

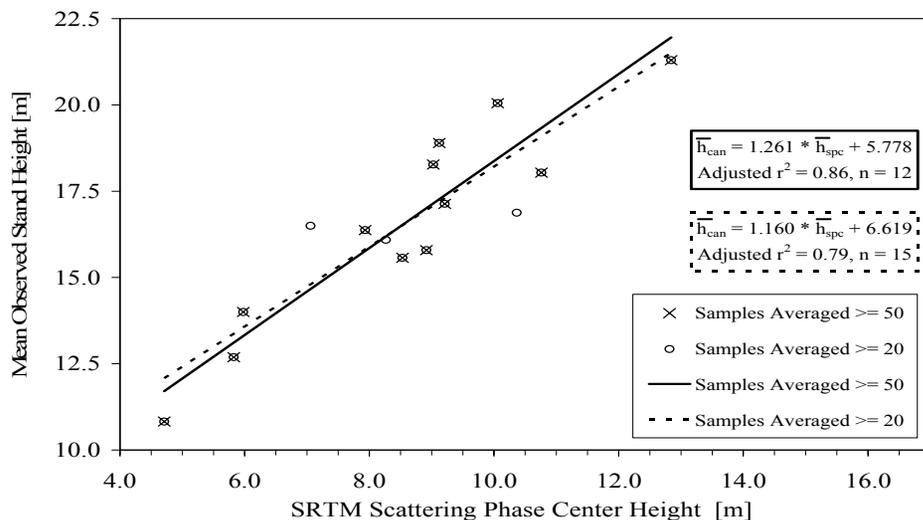
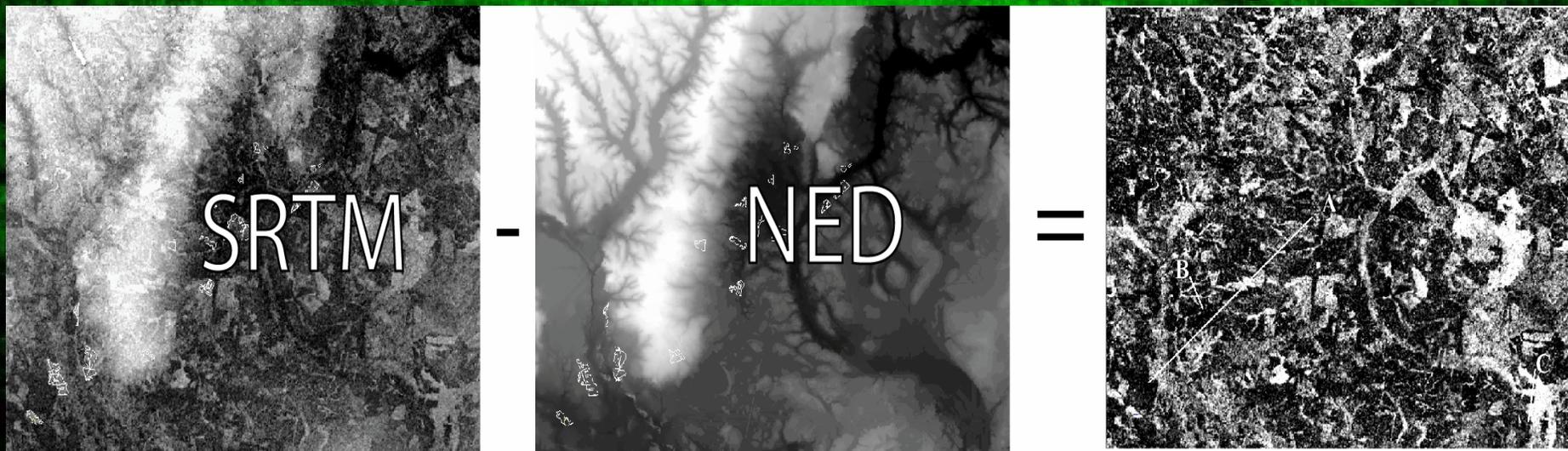


- A fundamental law of science applies to the analysis of SRTM data:
 - *"One scientist's noise is another scientist's signal!"*



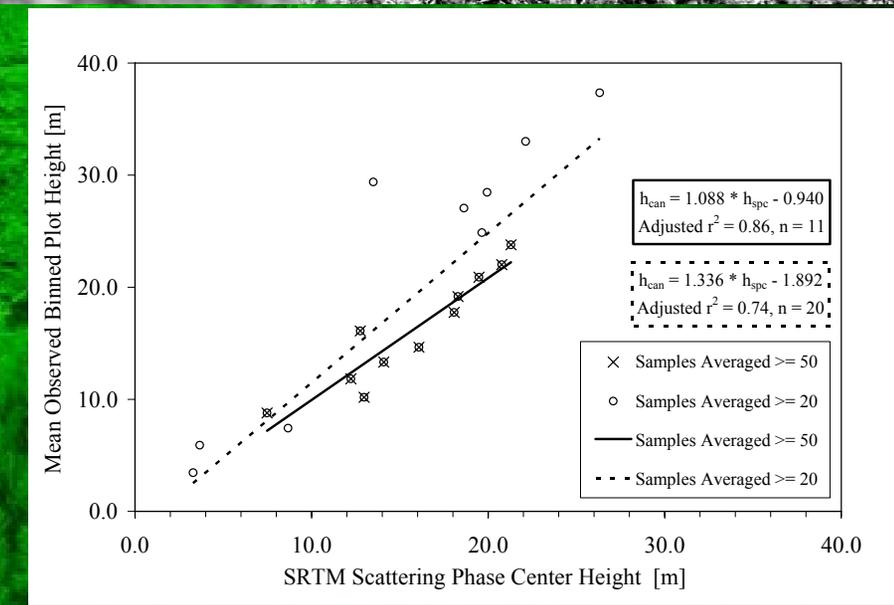
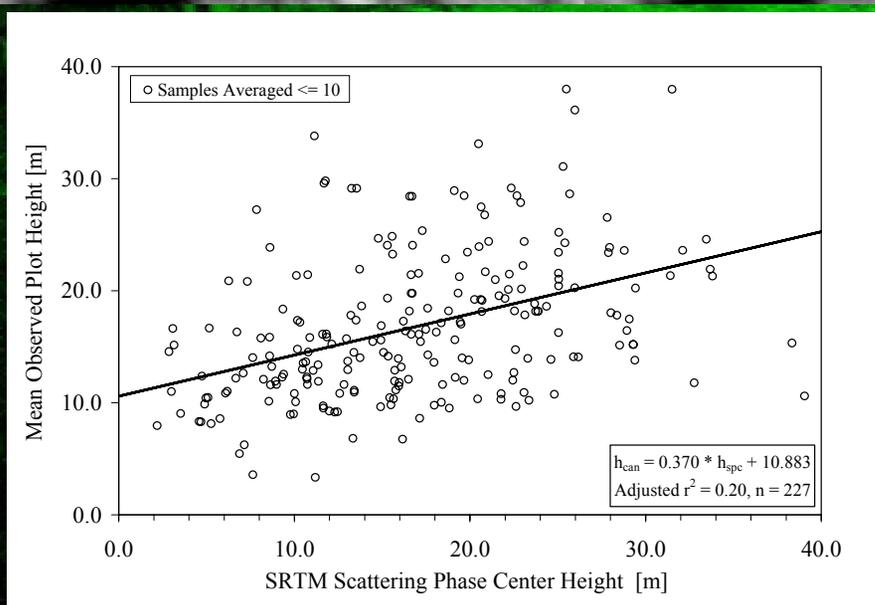
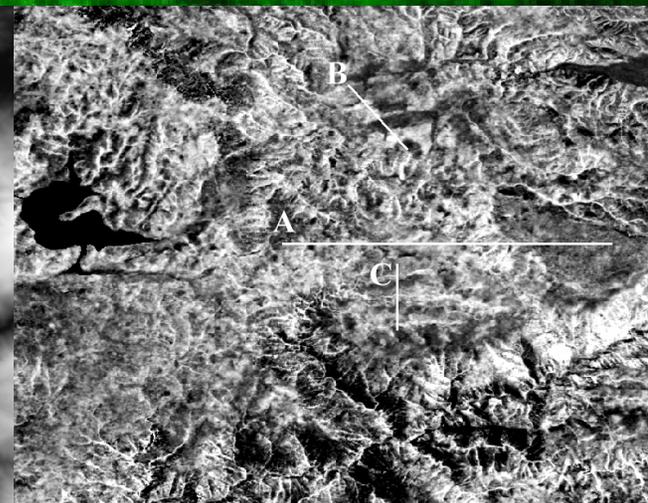
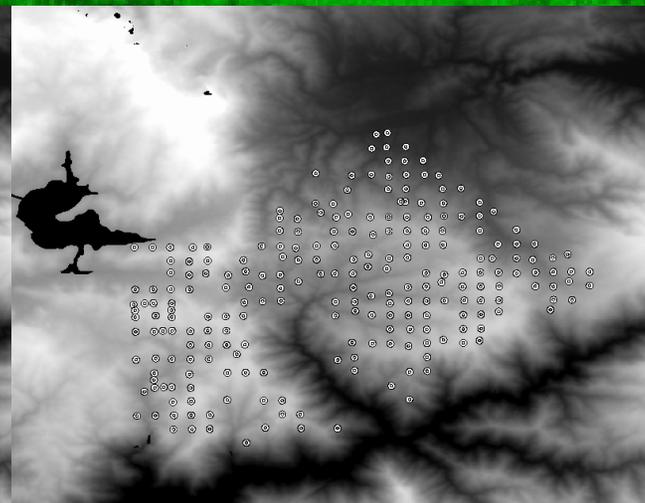
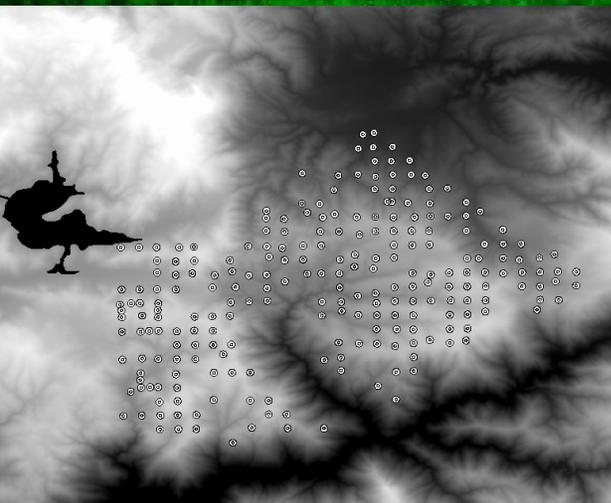
Geologist Ecologist

Pilot Studies for SRTM Height Retrieval: Georgia



- Kelldorfer, J.M., W.S. Walker and L.E. Pierce, M.C. Dobson, J. Fites, C. Hunsaker, J. Vona, M. Clutter, "***Vegetation height derivation from Shuttle Radar Topography Mission and National Elevation data sets.***" Remote Sensing of Environment, Vol. 93, No. 3, 339-358, 2004.

Pilot Studies for SRTM Height Retrieval: Sierra Nevada



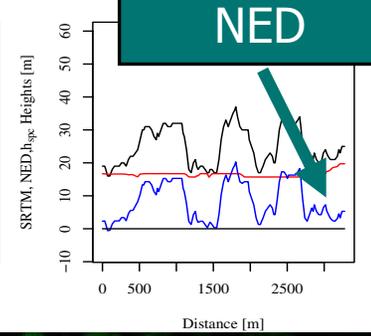
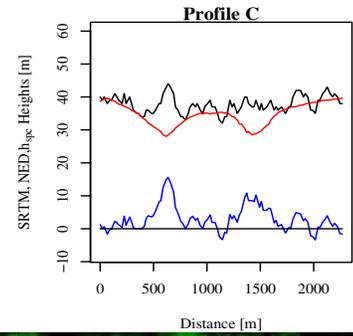
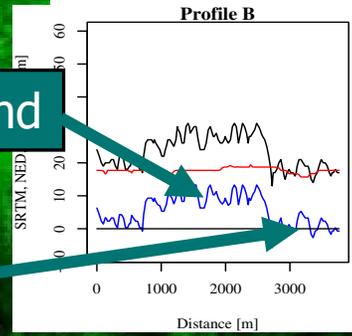
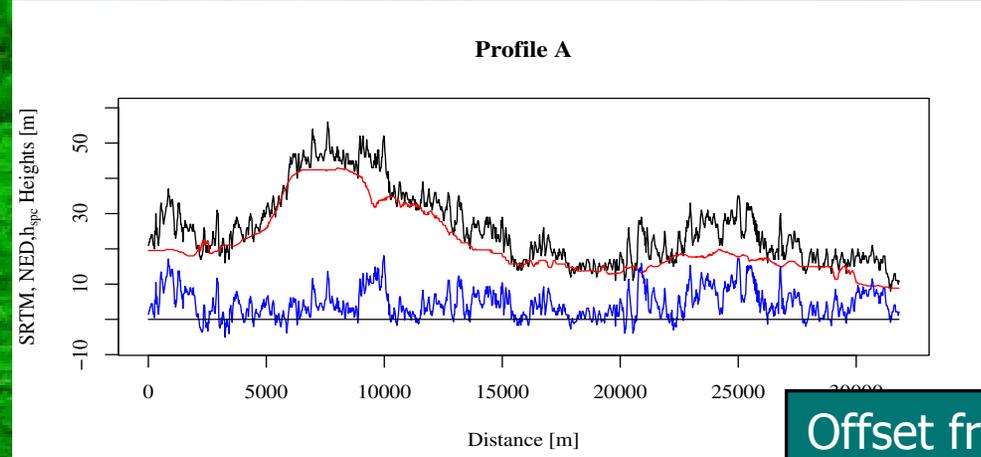
Where does the Noise come from?

- Seek to understand the noise and errors
 - Off what nature are those errors?
 - What is the magnitude ?
 - How can we mitigate the errors and reduce the noise?



Homogeneous Forest Stand

Bare Field

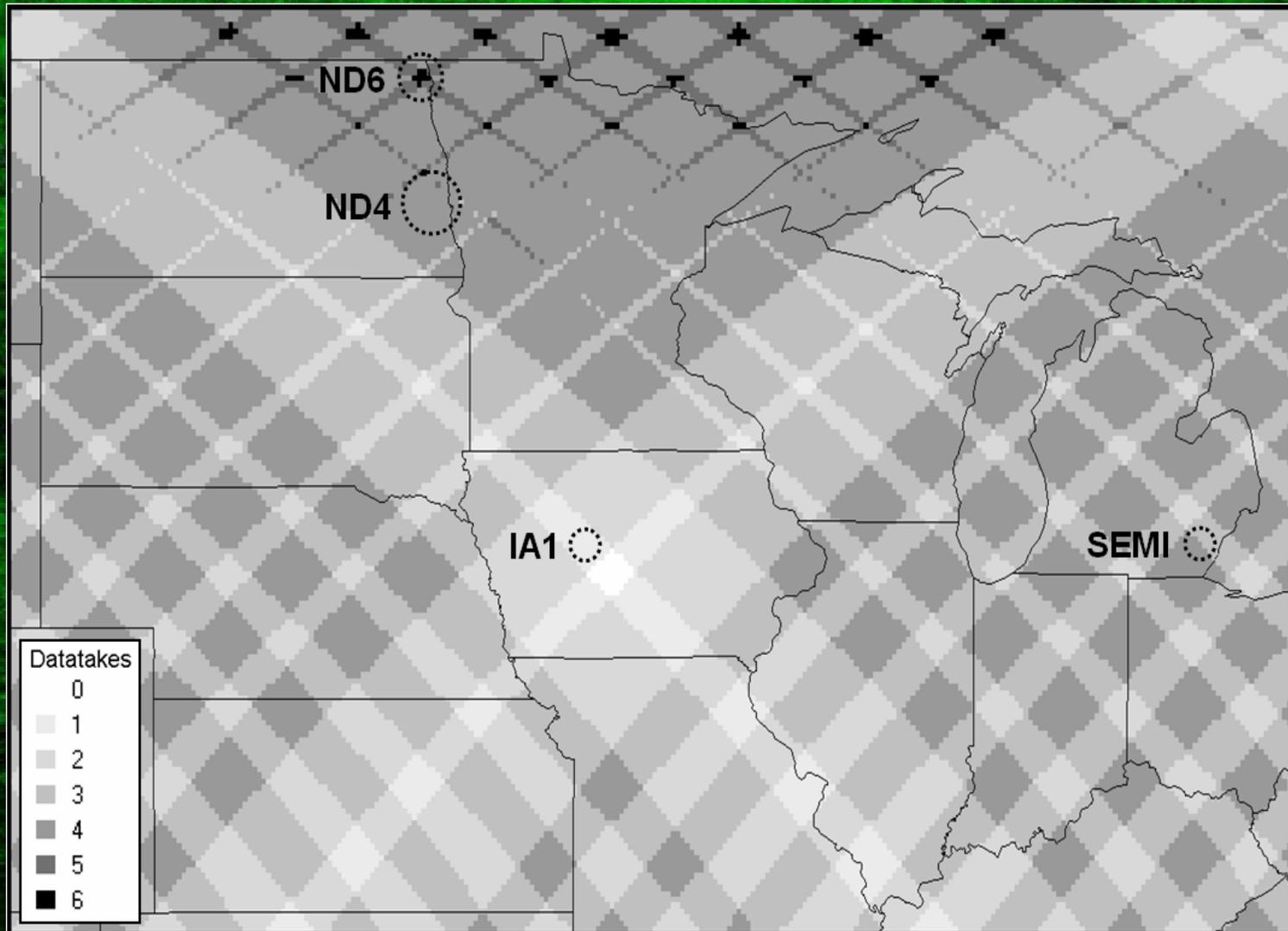


Offset from NED

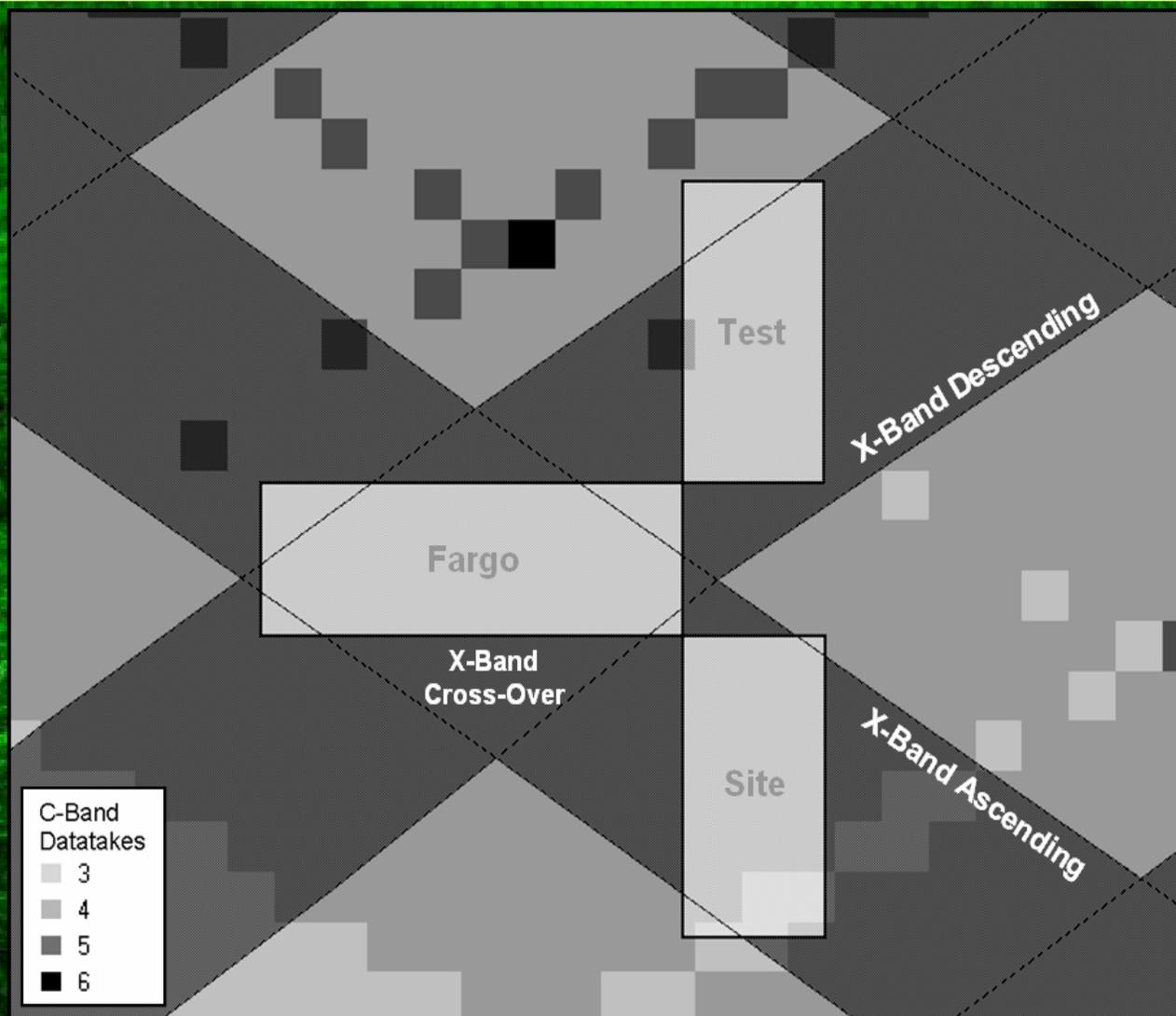
Study Design

- Choose areas of vegetation free surfaces
 - Large agricultural fields in Iowa and North Dakota
- Focus on areas where a range of data takes was available
- Target an area where both X- and C-band data were acquired
- For horizontal resolution estimation find “steps” in the landscape
 - Woodlots in South-East Michigan

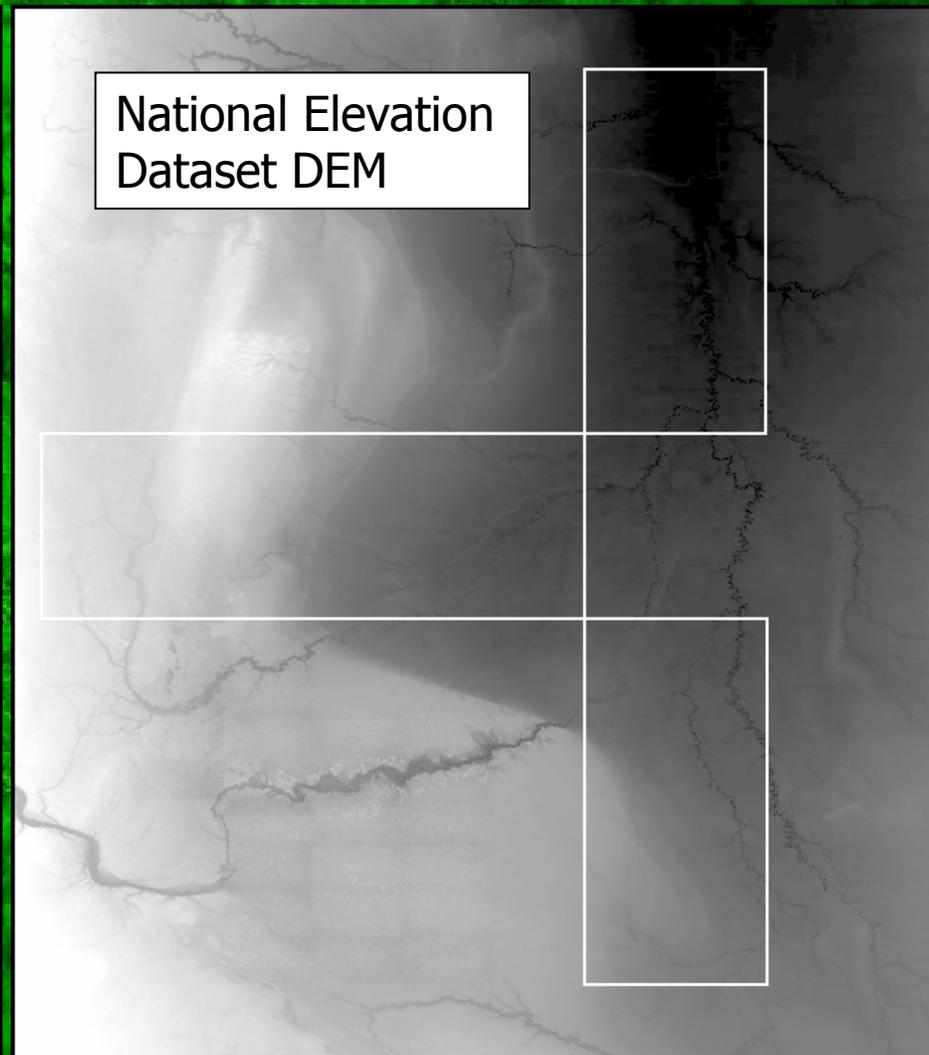
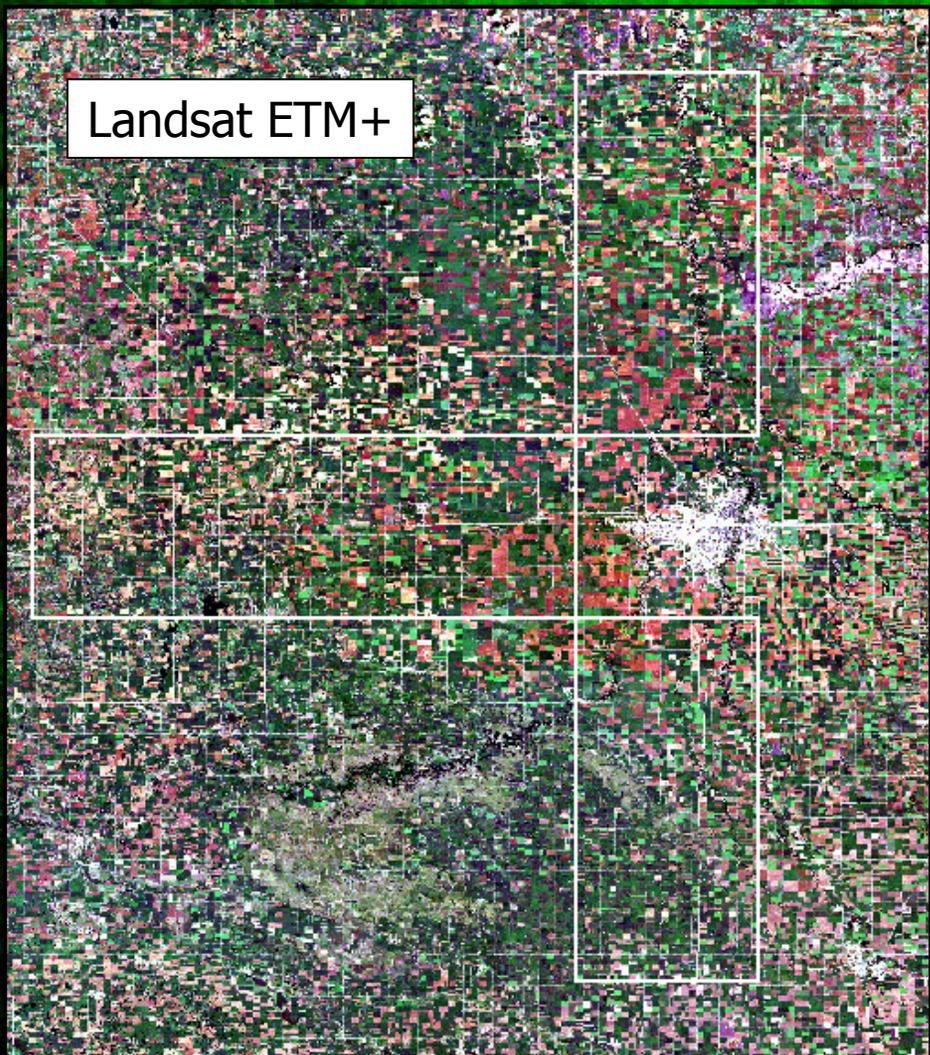
Test Site Locations



Test Site Fargo, Data Takes

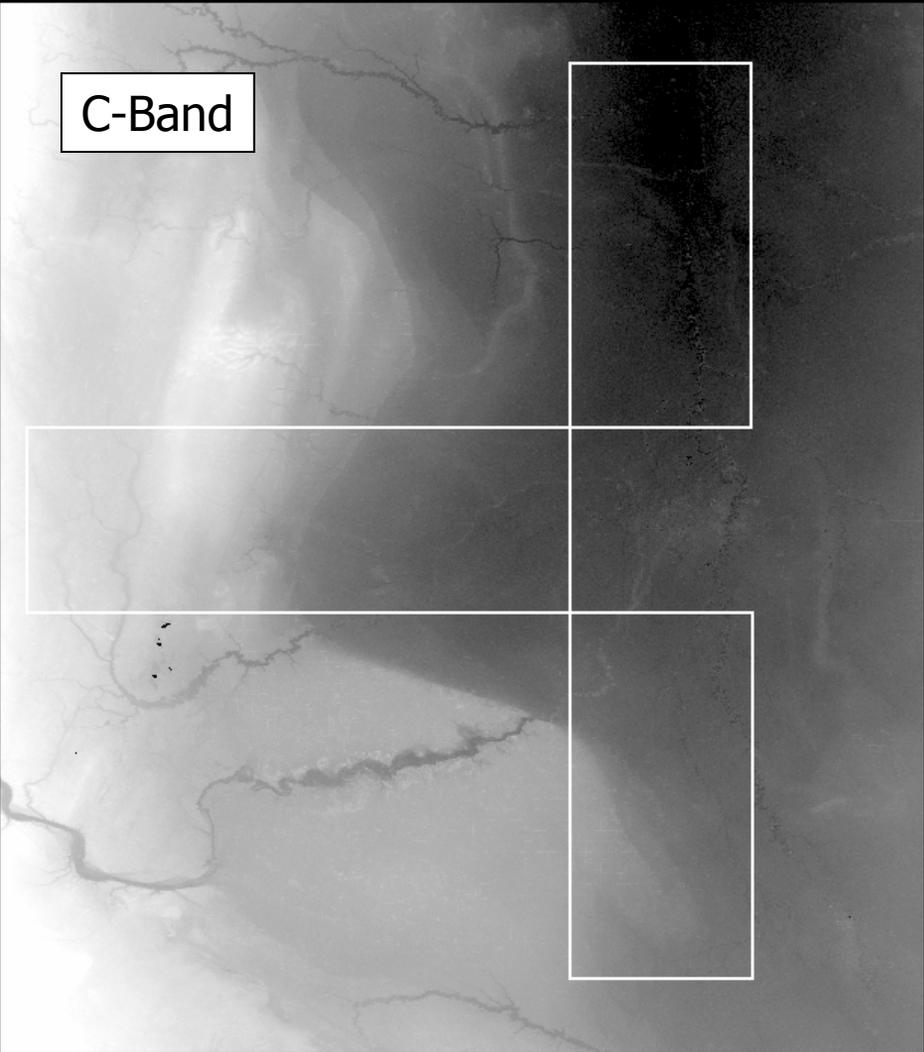


Landsat & NED Data

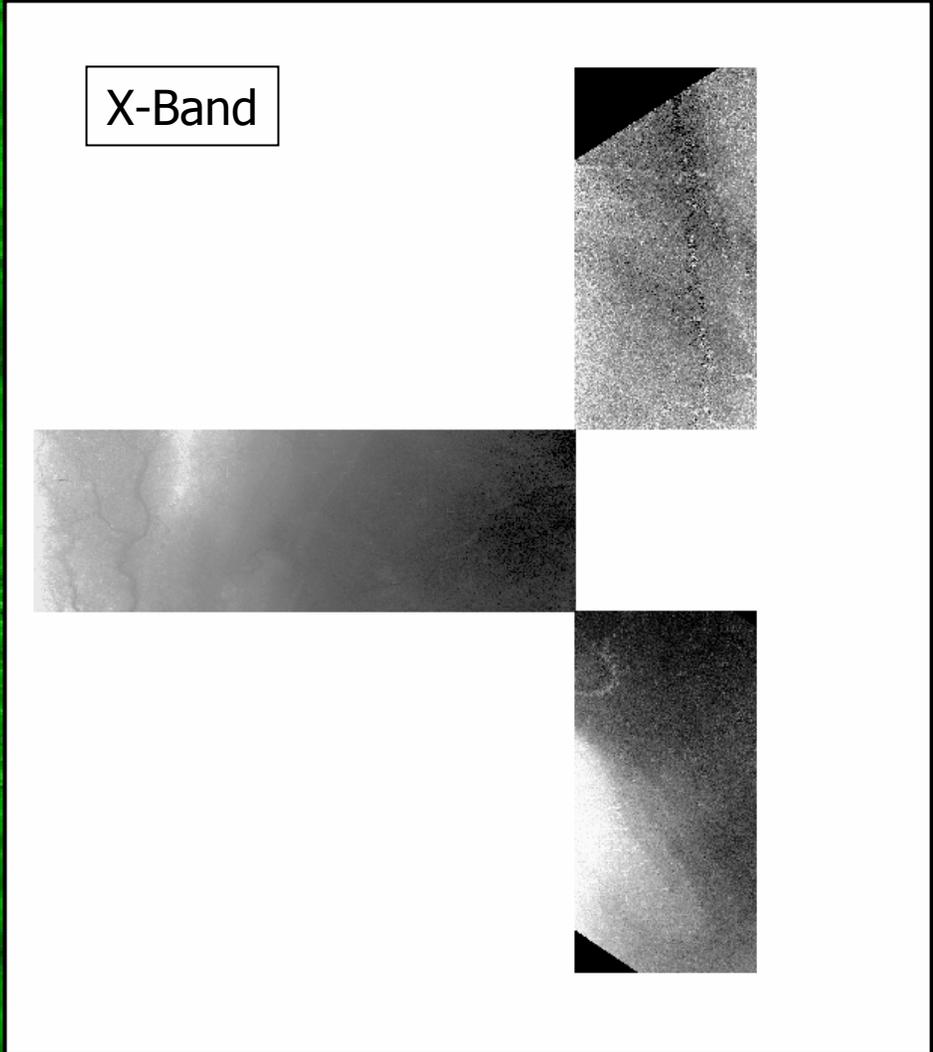


SRTM C- and X-Band

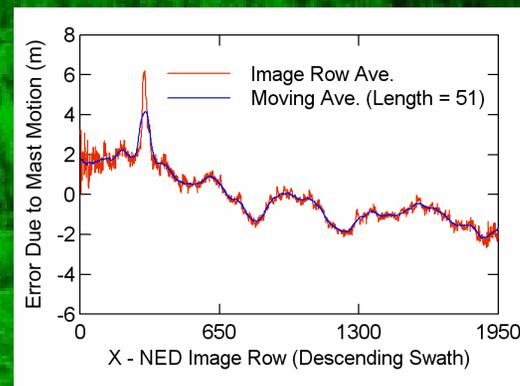
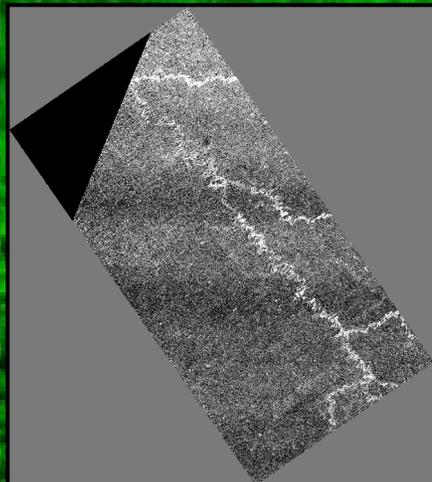
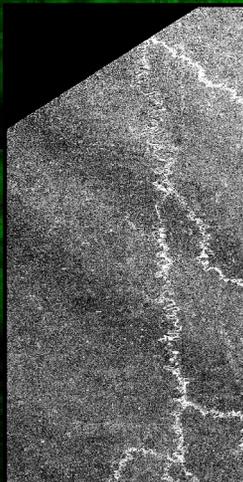
C-Band



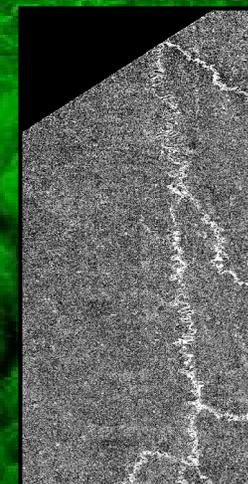
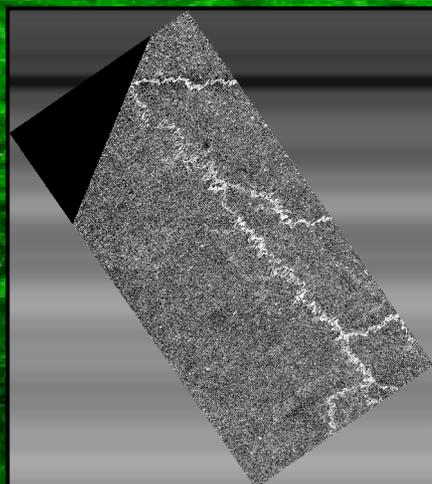
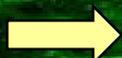
X-Band



Possible Correction Strategy



Mast motion error
function



X-band - NED
difference image with
mast motion error

Difference image after rotation

Difference image with error mitigated

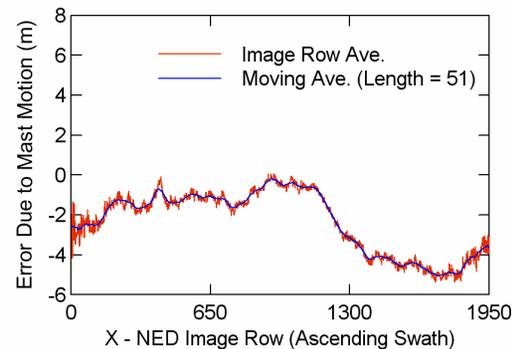
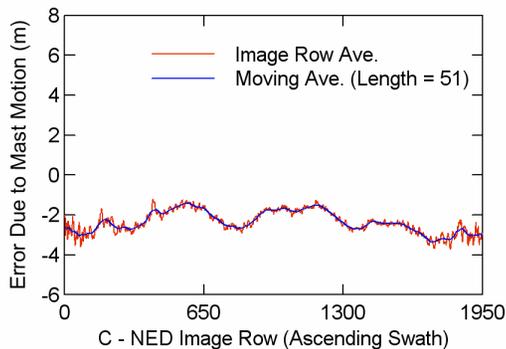
Difference image with
orientation restored

Mast Motion Analysis

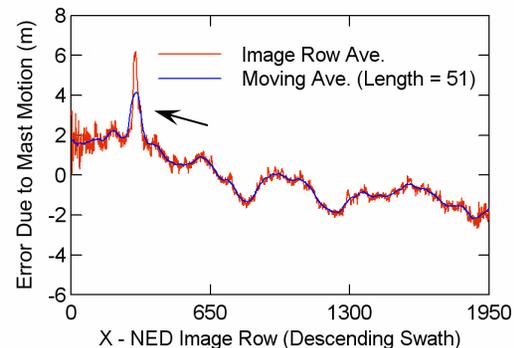
C-Band - NED

X-Band - NED

Ascending
Swath



Descending
Swath



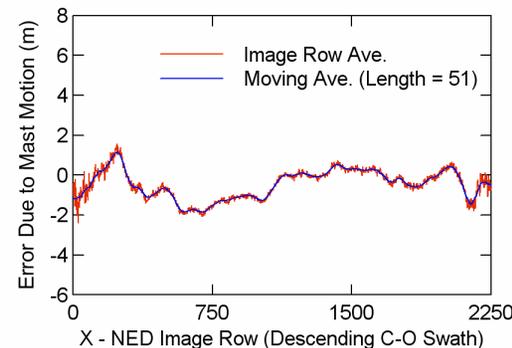
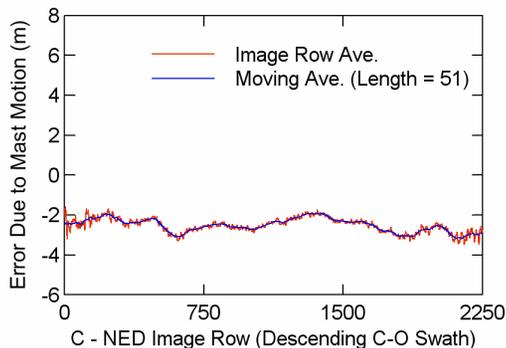
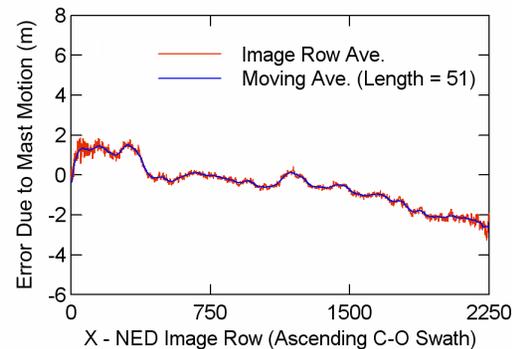
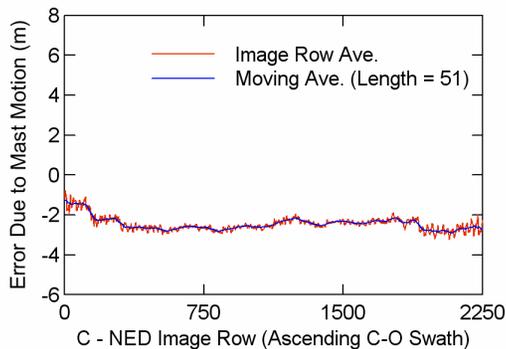
Mast Motion Analysis

Ascending
Portion of
Crossover
Region

Descending
Portion of
Crossover
Region

C-Band - NED

X-Band - NED



Mast Motion Correction Ascending Region

C-Band
Ascending Region

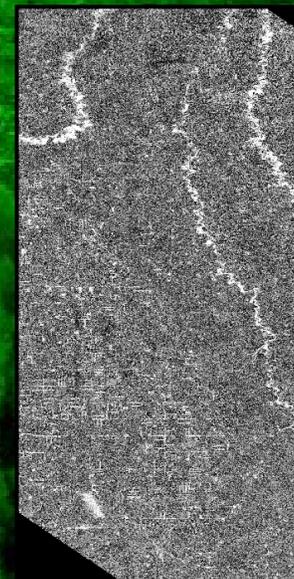
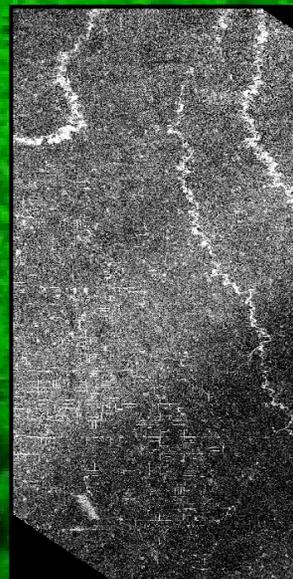
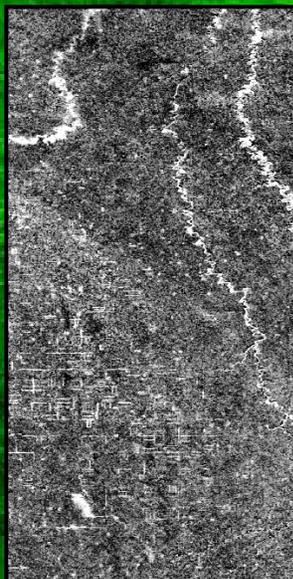
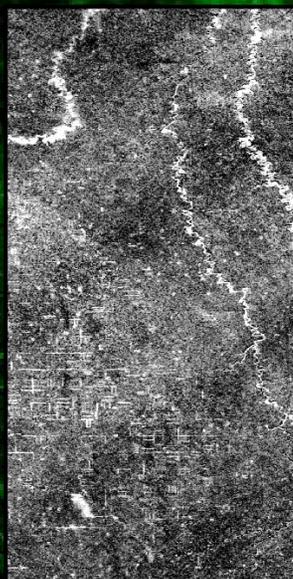
X-Band
Ascending Region

Before

After

Before

After



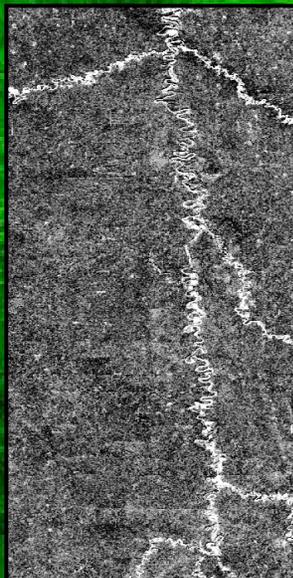
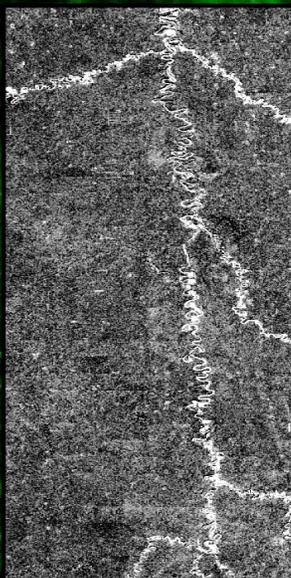
Mast Motion Correction Descending Region

C-Band
Descending Region

X-Band
Descending Region

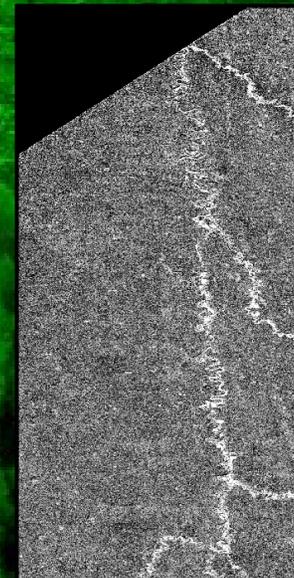
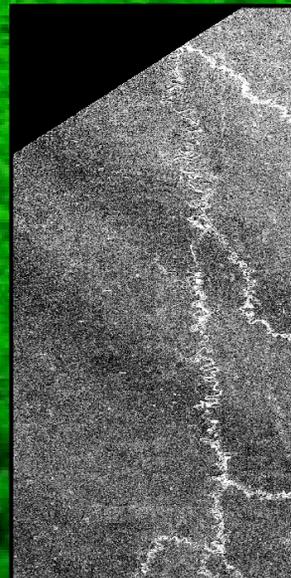
Before

After



Before

After

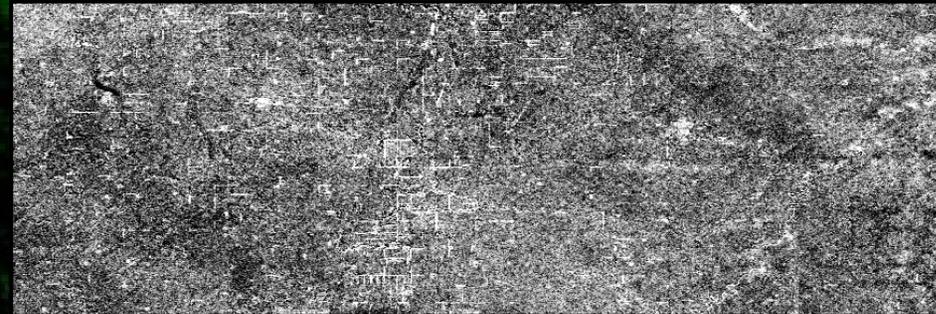


Mast Motion Correction Crossover Region

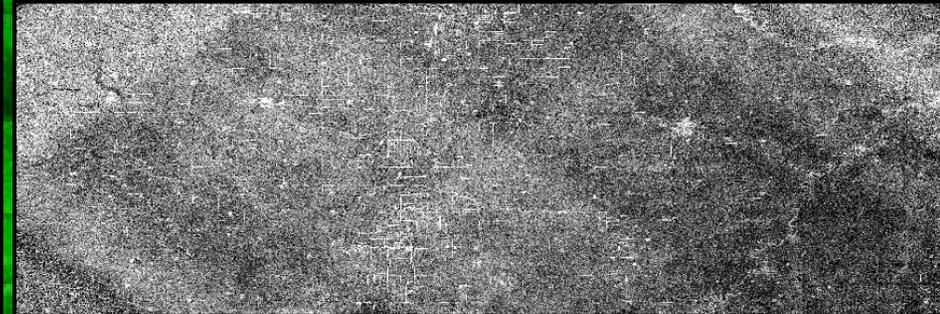
C-Band
Crossover Region

X-Band
Crossover Region

Before



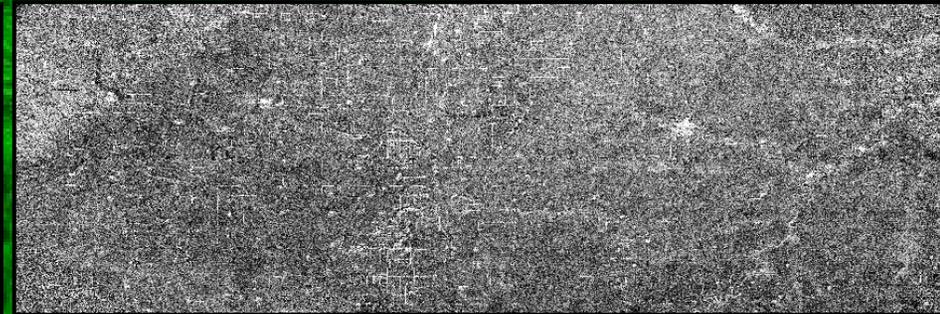
Before



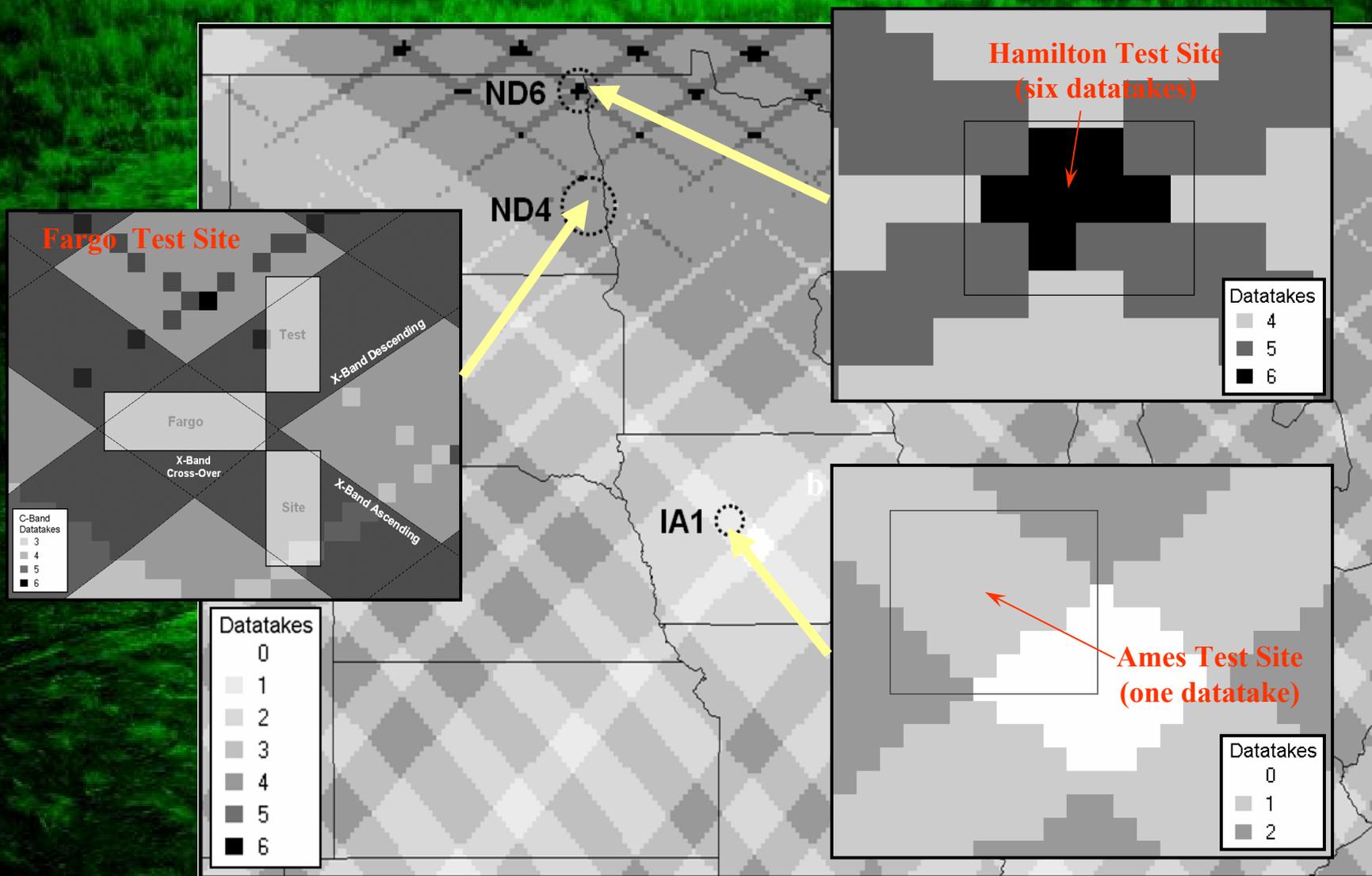
After



After

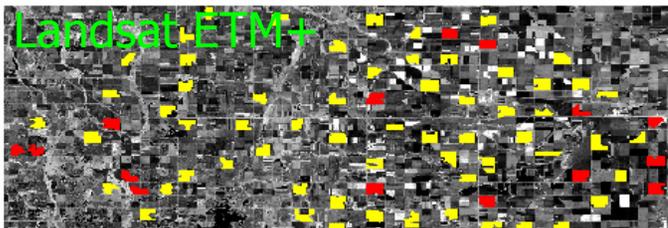
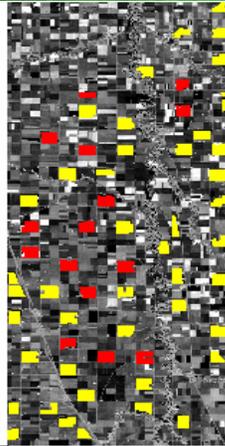


Phase Noise Analysis

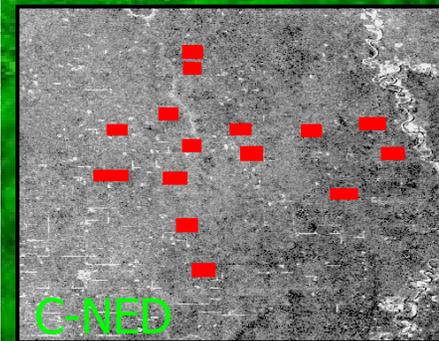
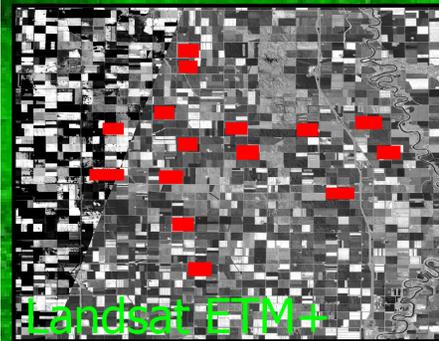


Phase Noise Analysis Field Sampling

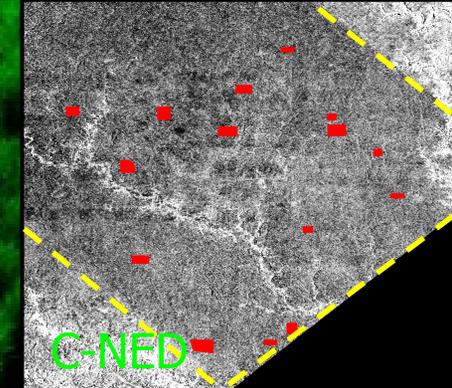
Fargo, North Dakota
C-Band 4 Data Takes
X-Band 1-2 Data Takes



Hamilton,
North Dakota
C-Band 6
Data Takes

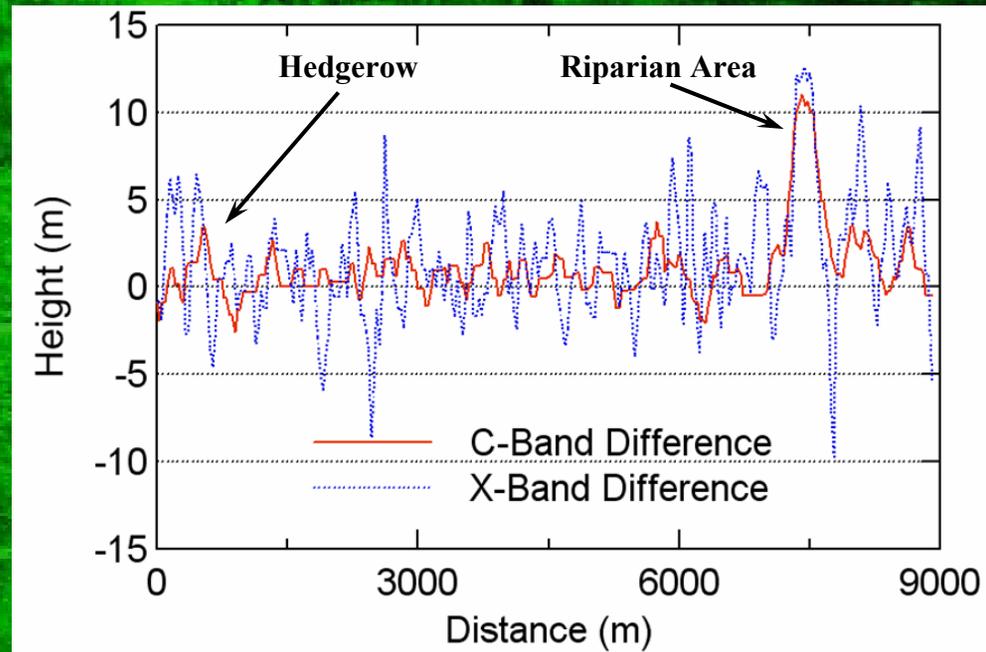
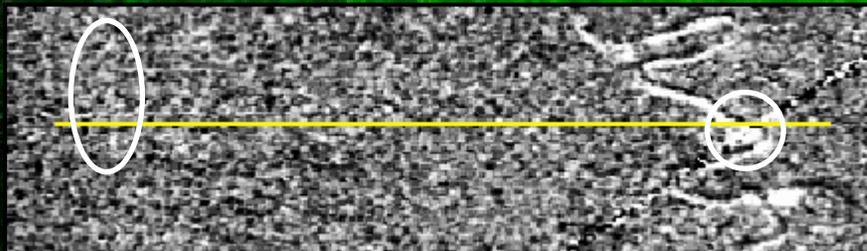
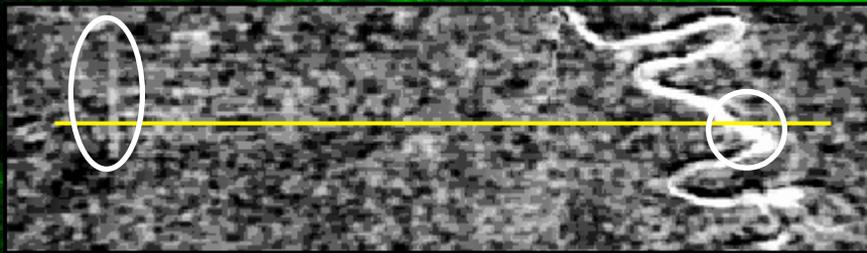
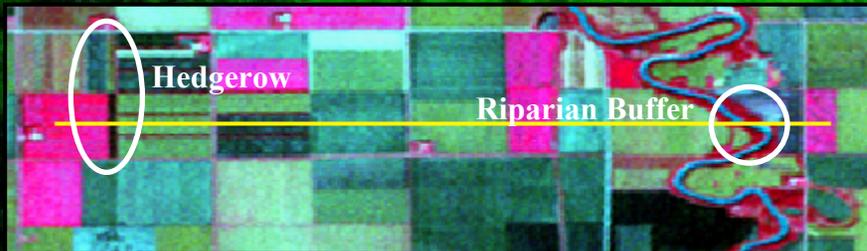


Ames,
Iowa
C-Band 1
Data Take



SRTM – NED Profile

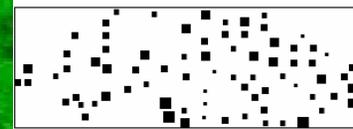
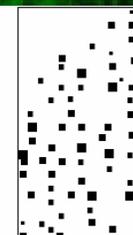
Fargo: Descending Path



Test on Location Dependency

	Number of Fields	Independent Variables	Dependent Variable	Adj. r^2	F-statistic	p-value
Fargo Descending						
C-Band Difference (Four Datatakes)	59	Latitude/ Longitude	Noise Range	0.00	0.70	>0.503
X-Band Difference (One Datatake)	59			0.14	5.82	>0.005
Fargo Cross-Over						
C-Band Difference (Four Datatakes)	76	Latitude/ Longitude	Noise Range	0.00	0.30	>0.744
X-Band Difference (Two Datatakes)	76			0.00	0.24	>0.791

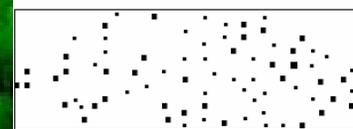
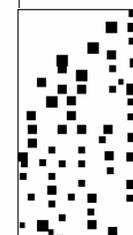
C-Band



Phase Noise Range (m)

- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10

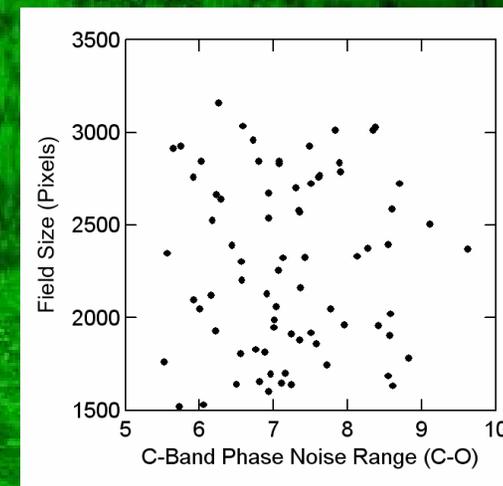
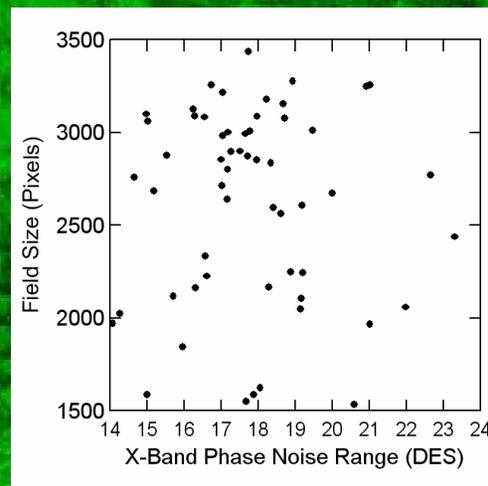
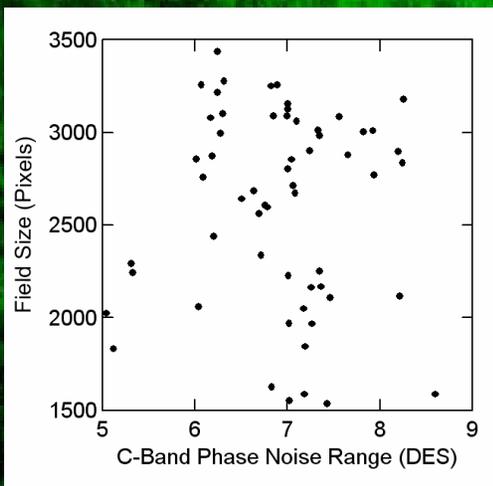
X-Band



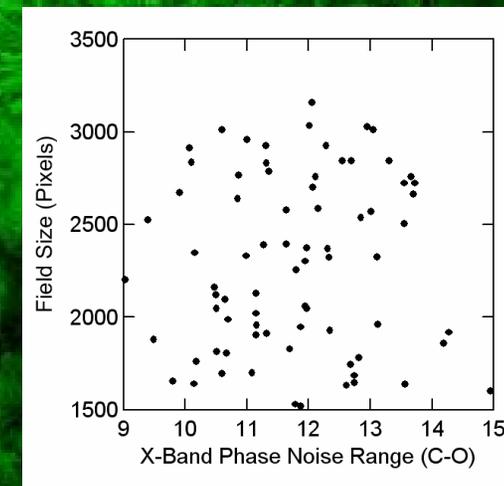
Phase Noise Range (m)

- 9 - 12
- 12 - 15
- 15 - 18
- 18 - 21
- 21 - 24

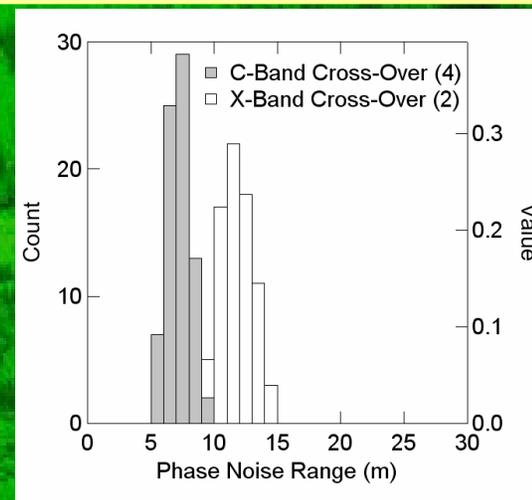
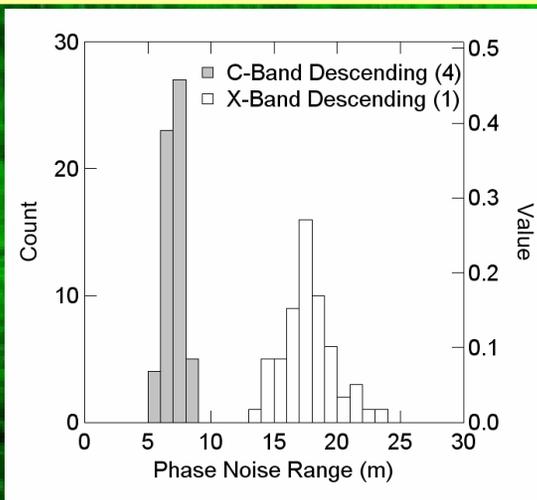
Test on Field Size Dependency



	Number of Fields	Independent Variable	Dependent Variable	Adj. r^2	F-statistic	p-value
Fargo Descending						
C-Band Difference (Four Datatakes)	59	Field Size (pixels)	Noise Range	0.00	0.01	>0.913
X-Band Difference (One Datatake)	59			0.00	0.05	>0.816
Fargo Cross-Over						
C-Band Difference (Four Datatakes)	76	Field Size (pixels)	Noise Range	0.00	0.01	>0.927
X-Band Difference (Two Datatakes)	76			0.00	0.23	>0.634

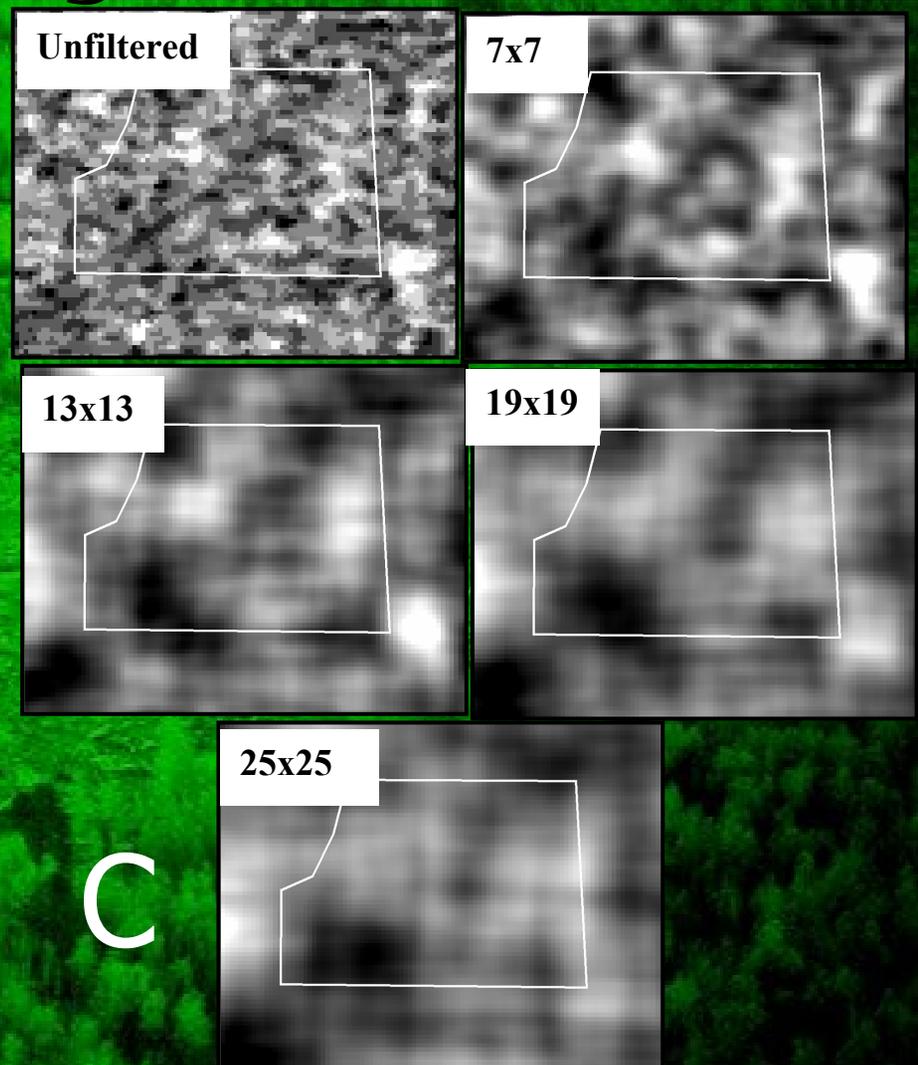
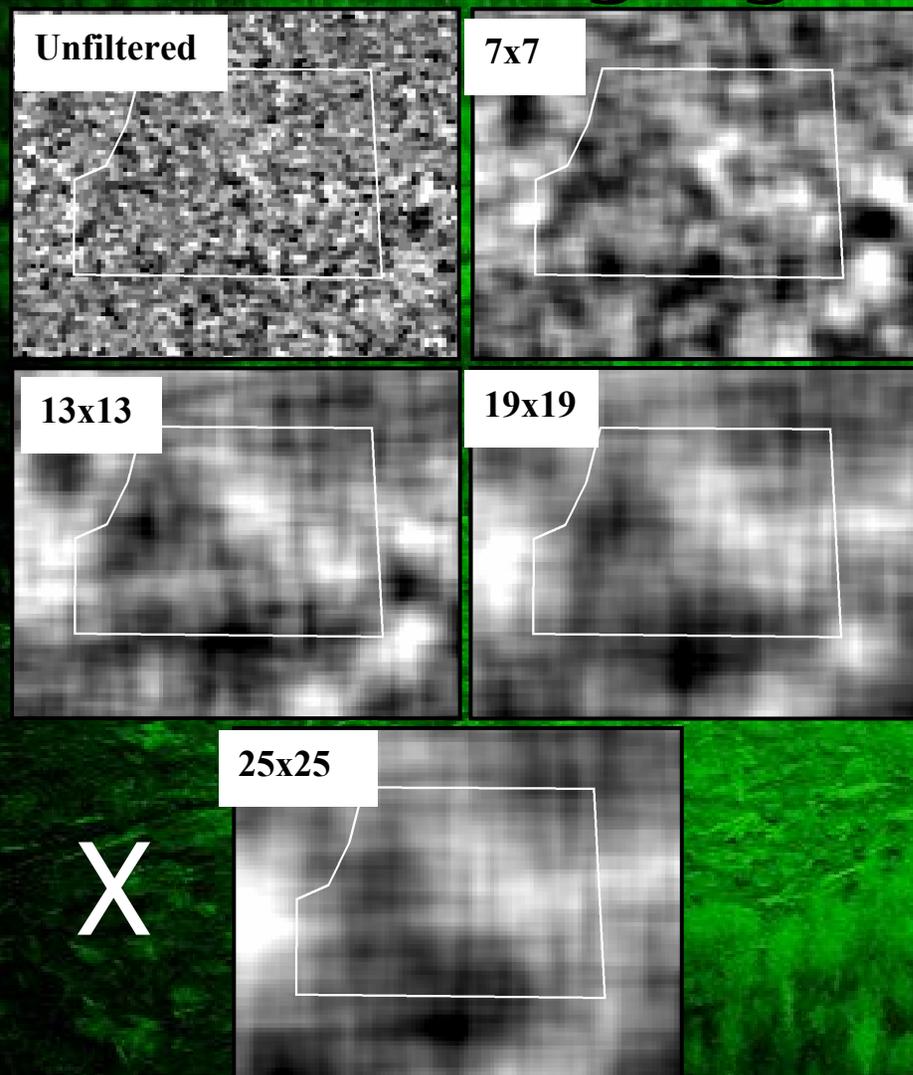


Noise Statistics Fargo

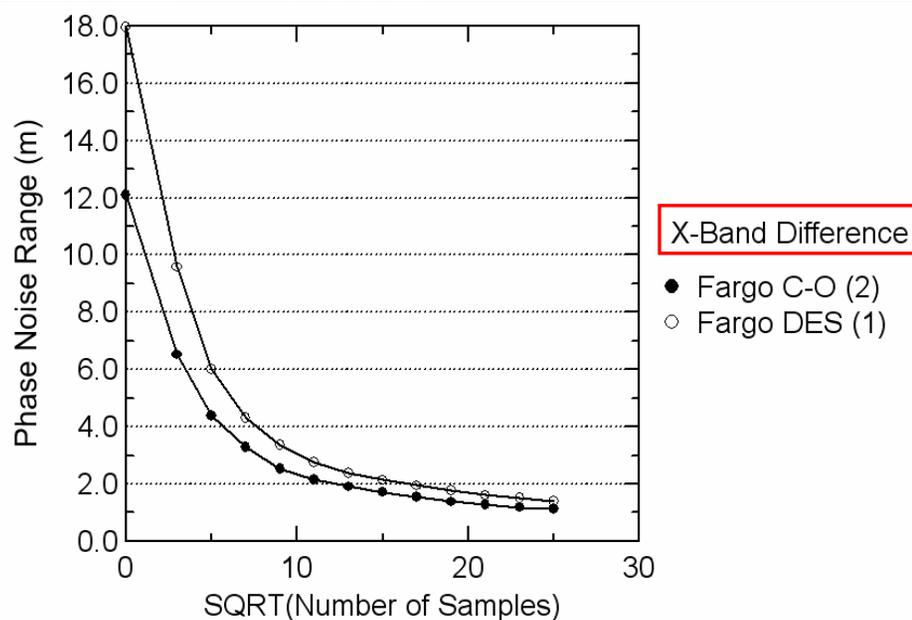
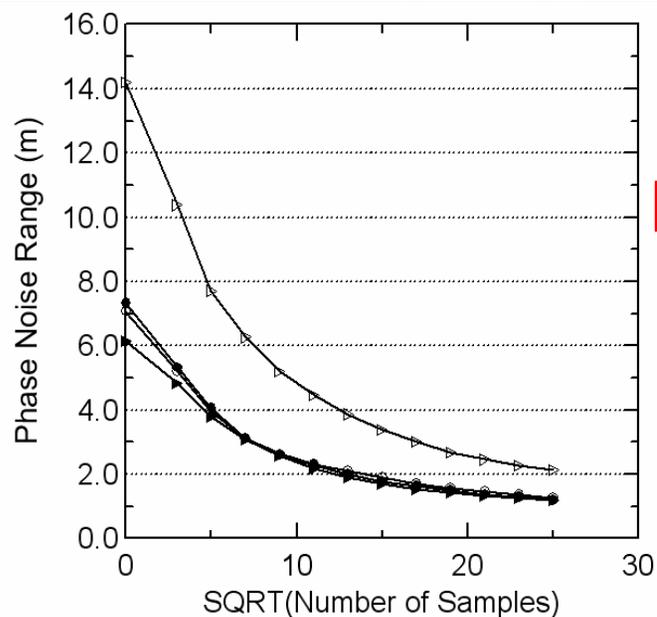


	Number of Fields	Min. Noise Range	Max. Noise Range	Range Noise Range	Mean Noise Range	Std. Dev. Noise Range	Mean Noise Mean	Std. Dev. Noise Mean
Fargo Descending								
C-Band Difference (Four <u>Datatakes</u>)	59	5.0	8.6	3.6	6.9	0.8	-0.19	0.27
X-Band Difference (One <u>Datatake</u>)	59	14.0	23.3	9.3	17.7	2.0	-0.18	0.30
Fargo Cross-Over								
C-Band Difference (Four <u>Datatakes</u>)	76	5.5	9.6	4.1	7.2	0.9	-1.31	0.33
X-Band Difference (Two <u>Datatakes</u>)	76	9.0	15.0	6.0	11.8	1.3	-0.44	0.49

Noise Reduction via Sample Averaging: Fargo Test Site



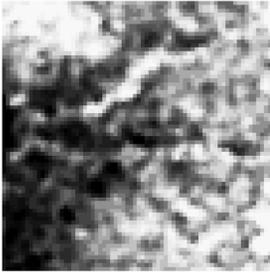
Sample Averaging Effects



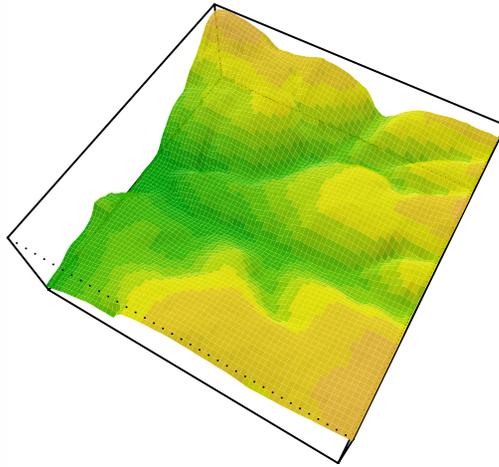
Sample Averaging Effects

Square Root (No. of Pixels)	Un- filter ed	3	5	7	9	11	13	15	17	19	21	23	25
C-Band Difference Phase Noise													
One Datatake (Ames)	14.2 (1.2)	10.4 (1.3)	7.7 (1.2)	6.3 (1.0)	5.2 (0.9)	4.5 (0.9)	3.9 (0.8)	3.4 (0.7)	3.0 (0.7)	2.7 (0.7)	2.5 (0.7)	2.3 (0.6)	2.1 (0.6)
Four Datatakes (Fargo DES)	7.1 (0.8)	5.2 (0.5)	4.0 (0.4)	3.1 (0.4)	2.6 (0.4)	2.3 (0.4)	2.1 (0.3)	1.9 (0.3)	1.7 (0.4)	1.6 (0.3)	1.5 (0.3)	1.4 (0.3)	1.3 (0.3)
Four Datatakes (Fargo C-O)	7.3 (0.8)	5.3 (0.7)	4.1 (0.7)	3.1 (0.6)	2.6 (0.5)	2.3 (0.5)	2.0 (0.5)	1.8 (0.6)	1.6 (0.5)	1.5 (0.6)	1.4 (0.5)	1.3 (0.5)	1.2 (0.5)
Six Datatakes (Hamilton)	6.1 (0.4)	4.8 (0.5)	3.8 (0.5)	3.1 (0.5)	2.6 (0.5)	2.2 (0.4)	1.9 (0.4)	1.7 (0.4)	1.5 (0.4)	1.4 (0.4)	1.3 (0.4)	1.3 (0.3)	1.2 (0.3)
X-Band Difference Phase Noise													
One Datatake (Fargo DES)	18.0 (1.3)	9.6 (0.6)	6.0 (0.5)	4.3 (0.5)	3.4 (0.3)	2.8 (0.2)	2.4 (0.2)	2.1 (0.3)	1.9 (0.3)	1.8 (0.3)	1.6 (0.2)	1.5 (0.2)	1.4 (0.2)
Two Datatakes (Fargo C-O)	12.1 (1.1)	6.5 (0.5)	4.4 (0.4)	3.3 (0.3)	2.5 (0.4)	2.1 (0.6)	1.9 (0.5)	1.7 (0.5)	1.5 (0.5)	1.4 (0.5)	1.3 (0.4)	1.2 (0.4)	1.1 (0.4)

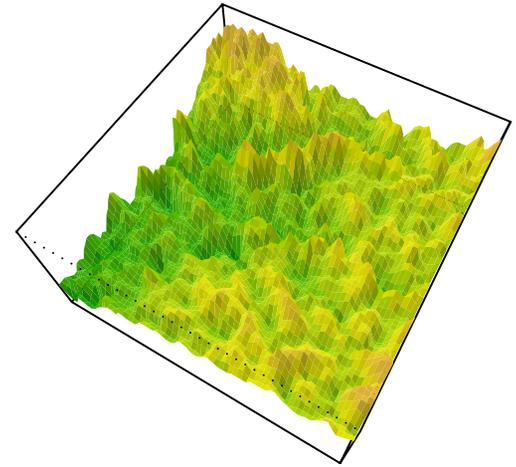
The Vegetation Focus: Smart Averaging



NED Heights



SRTM Heights

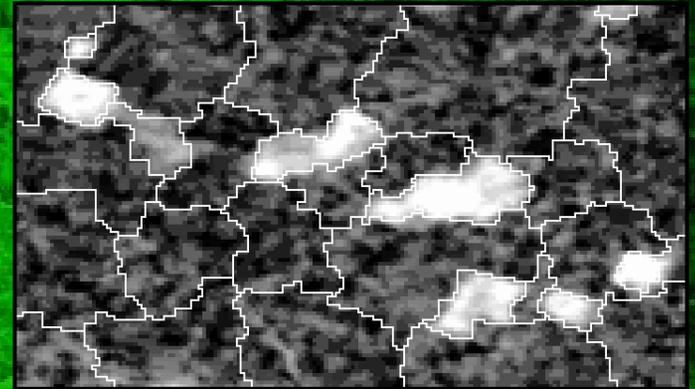


Michigan Woodlots

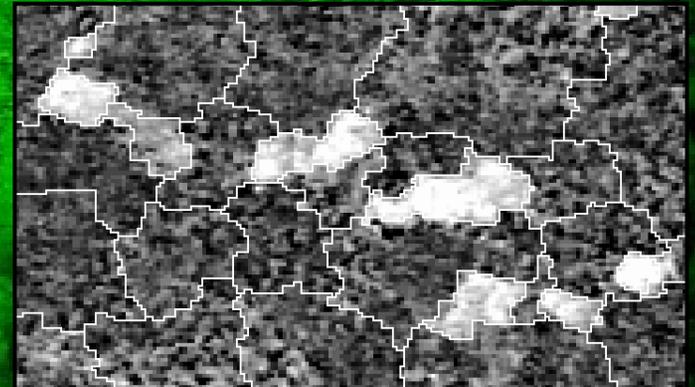
Airphoto



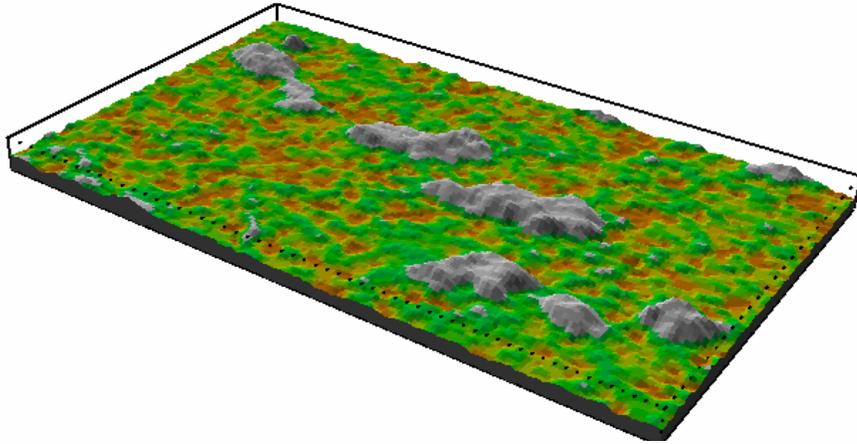
C



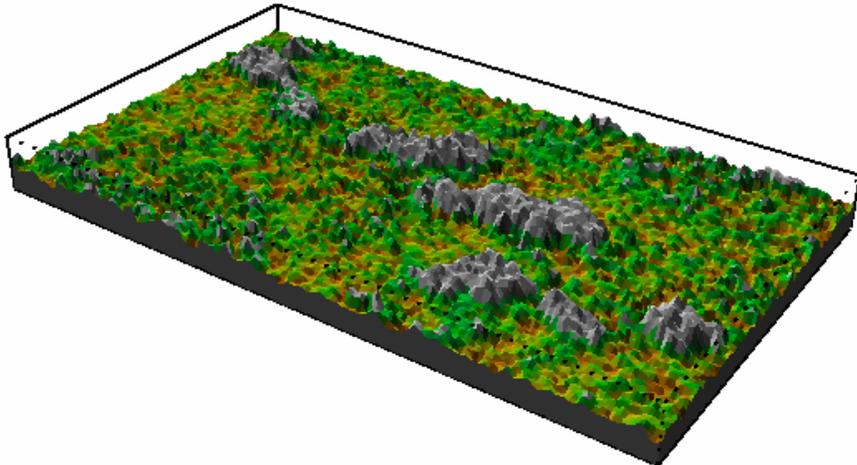
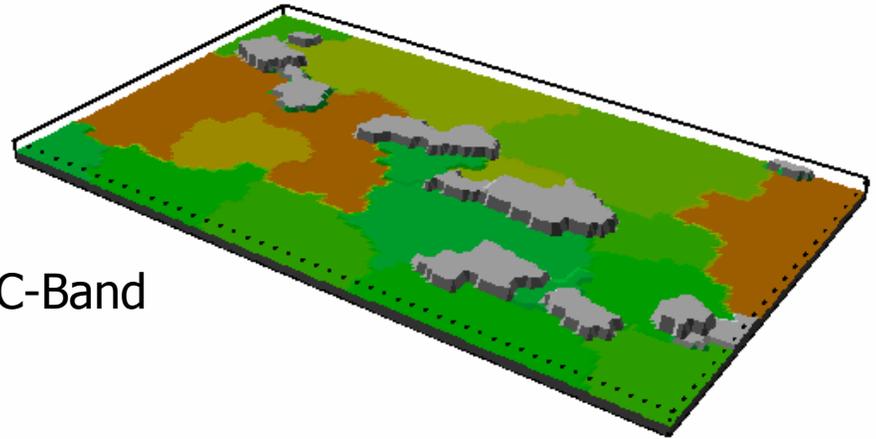
X



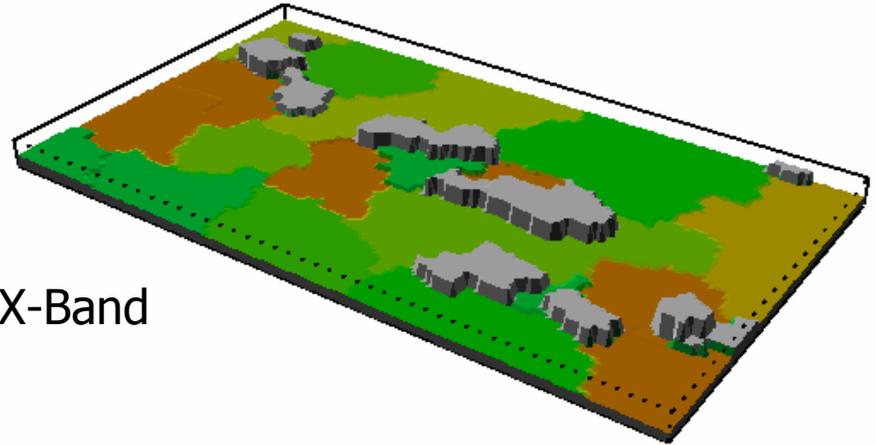
Michigan Woodlots



C-Band



X-Band

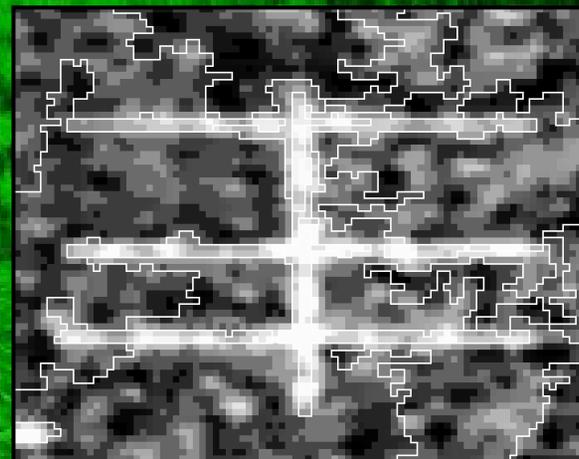


Iowa Hedgerows

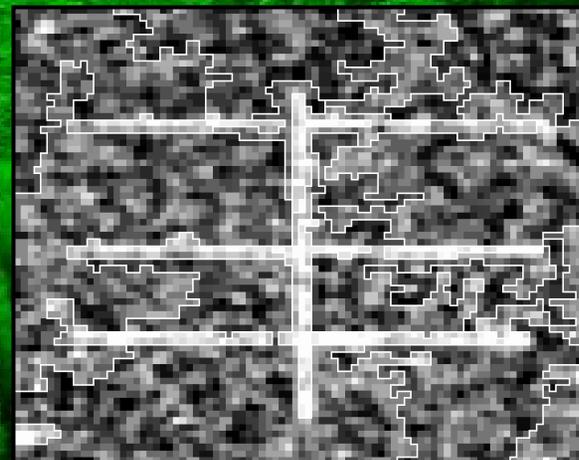
Airphoto



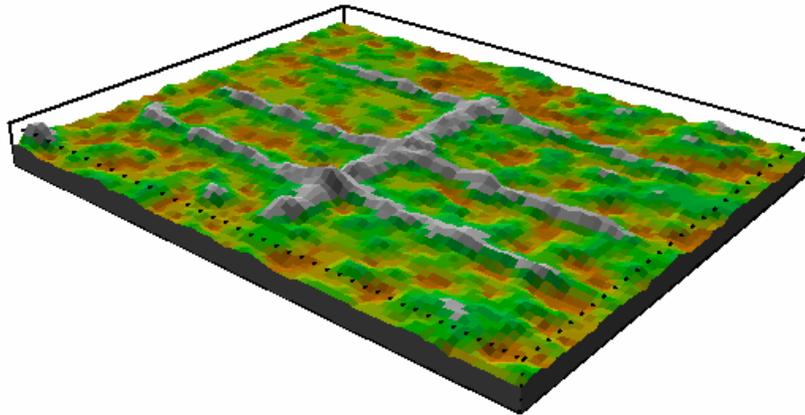
C



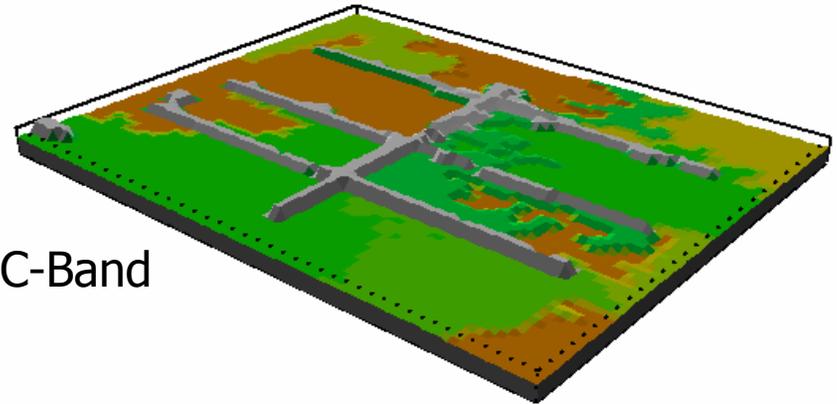
X



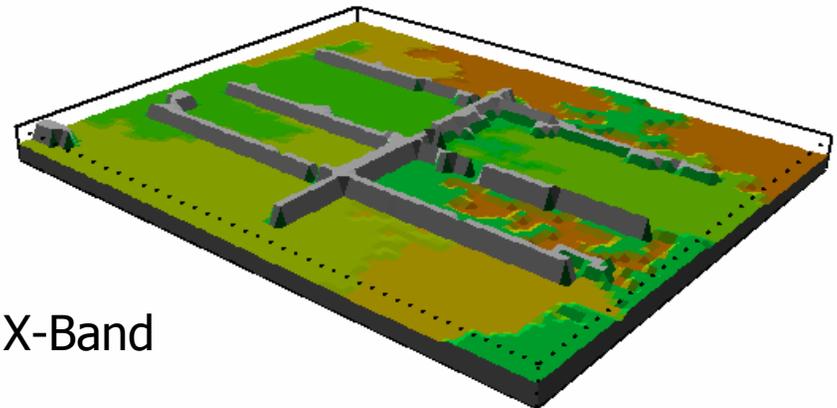
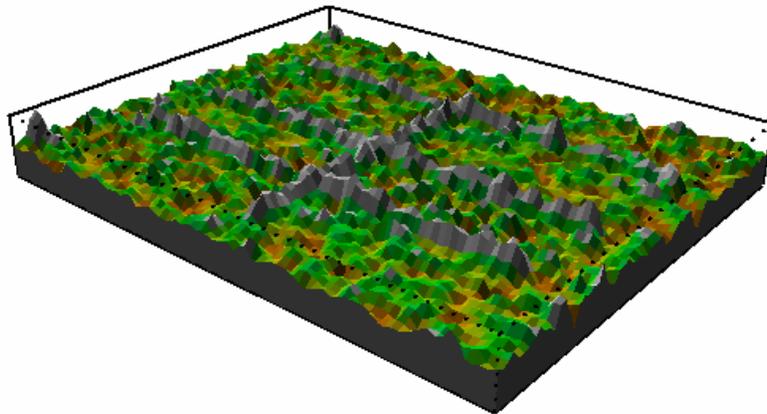
Iowa Hedgerows



C-Band

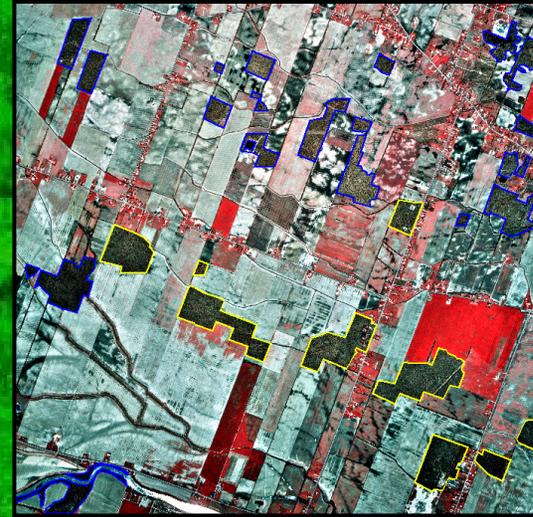


X-Band



Estimation of Horizontal Resolution

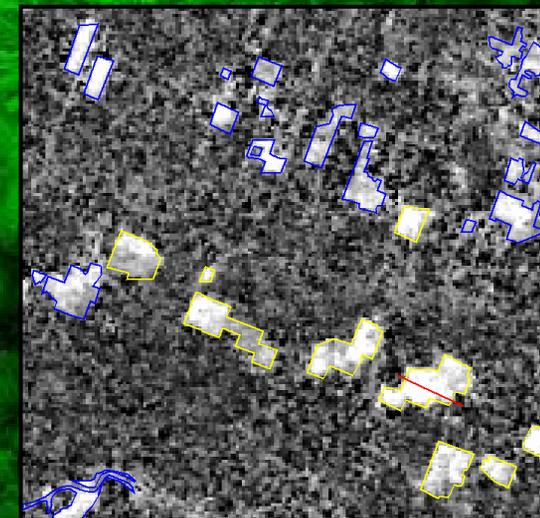
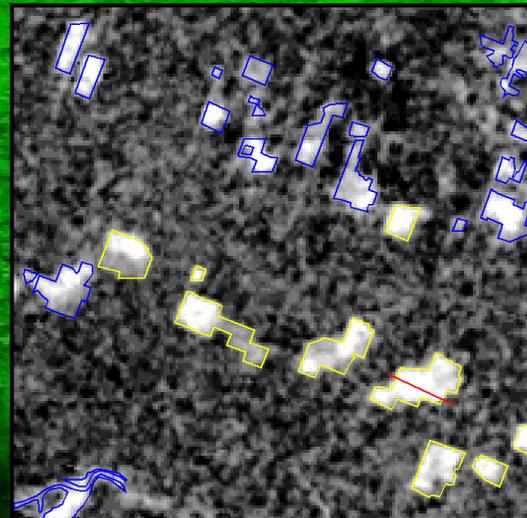
- South-East Michigan Test Site
 - Measurement of Natural Step-Functions (Woodlots)



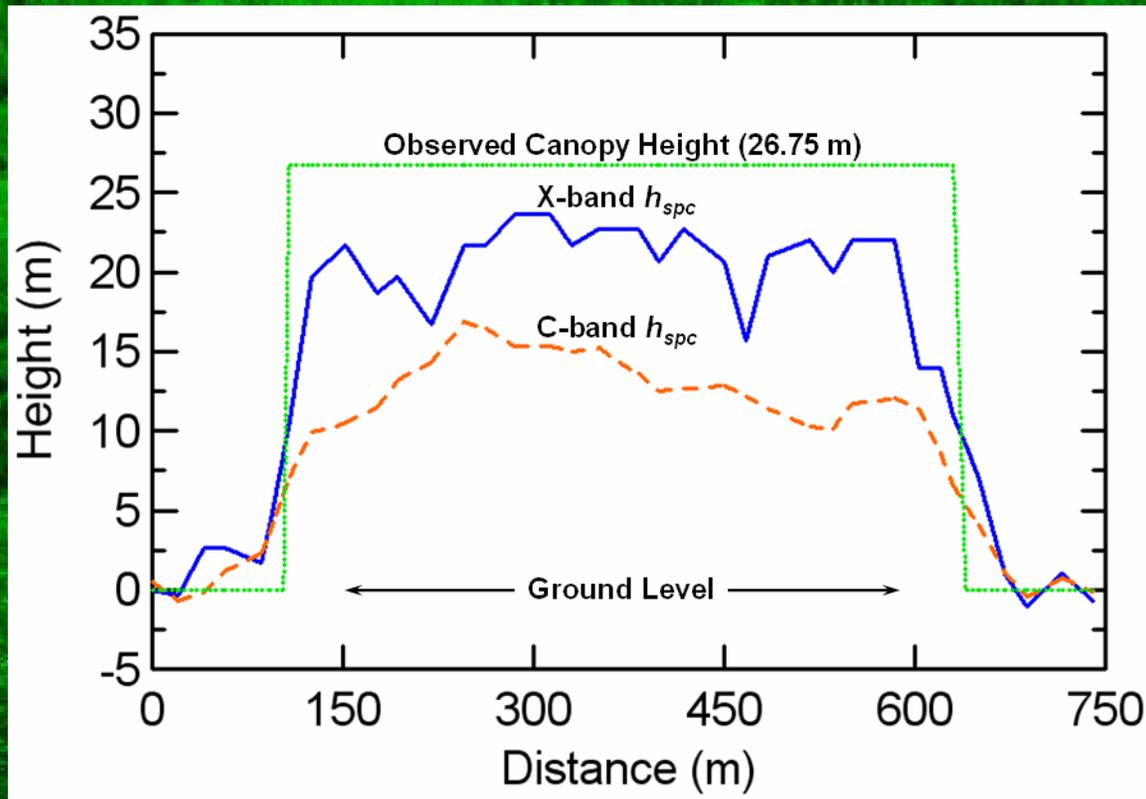
Airphoto

C

X



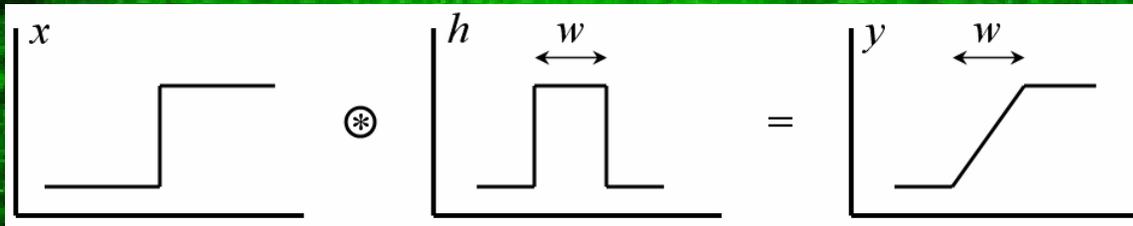
Forest Edge Observations



Observations of "ramping" effects
due to the filtering process

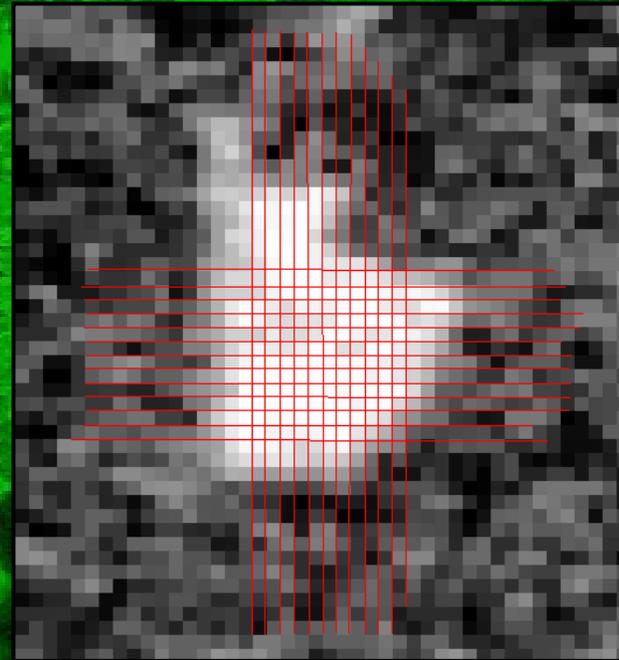
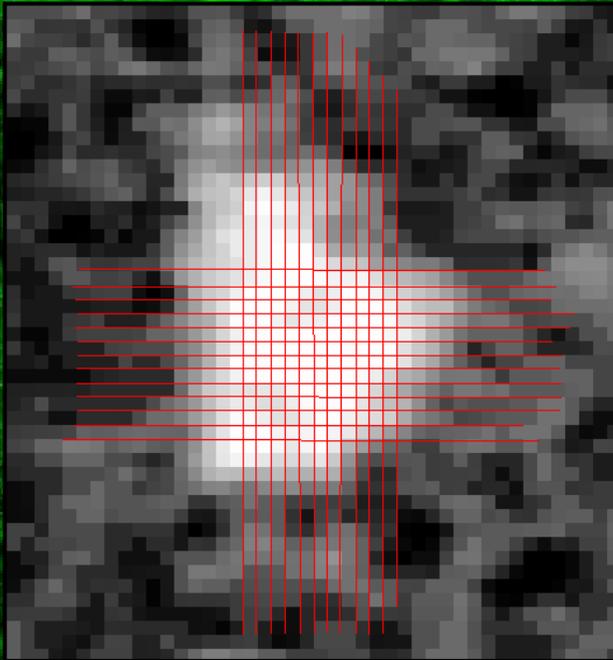
Filtering Effects on Forest Edges

Convolution of a step (input) function (x) with a rectangular impulse response (h) results in a ramped (output) function (y).



Measuring Forest Edges

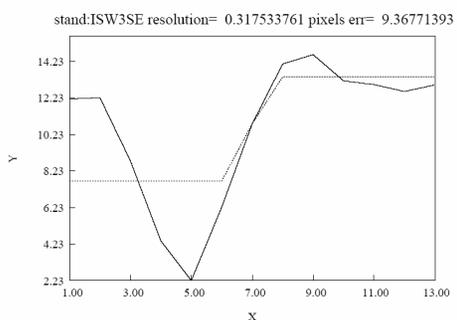
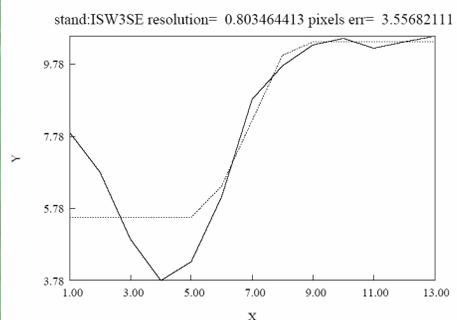
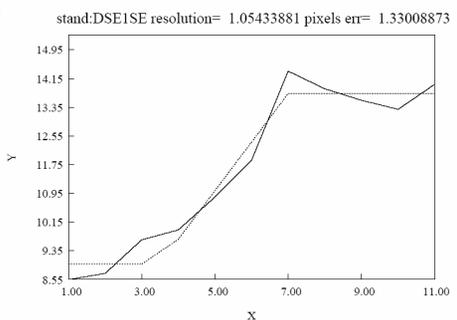
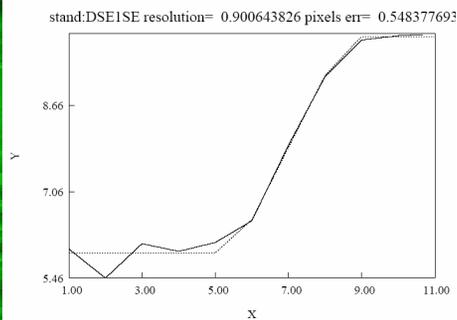
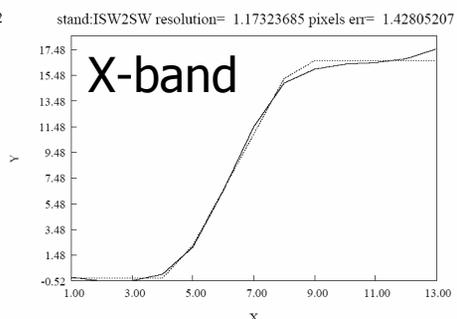
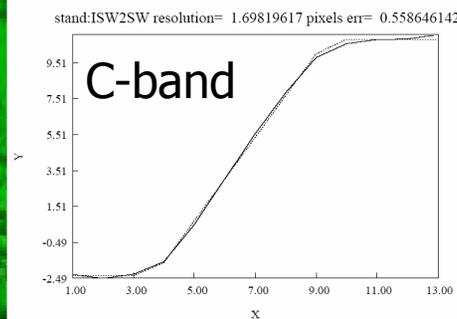
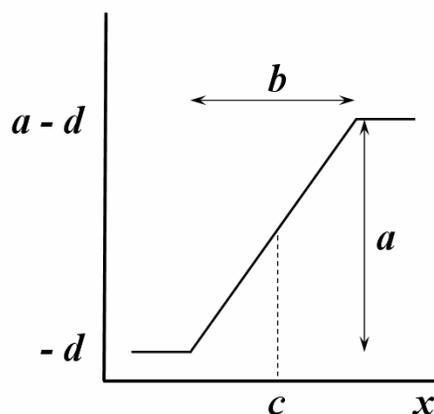
- Generation of noise-reduced forest edge functions through profile averaging



Measuring and Modeling Forest Edges

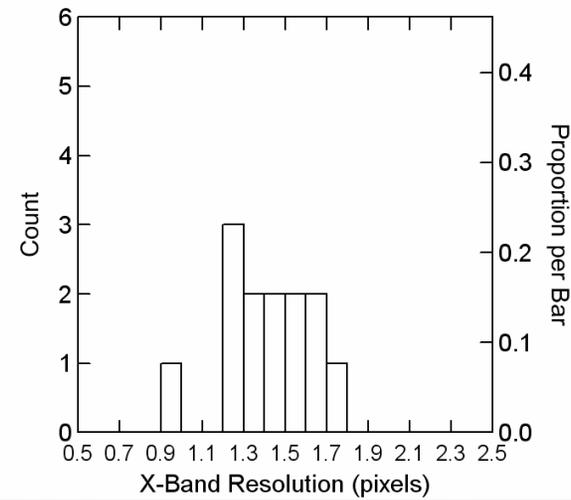
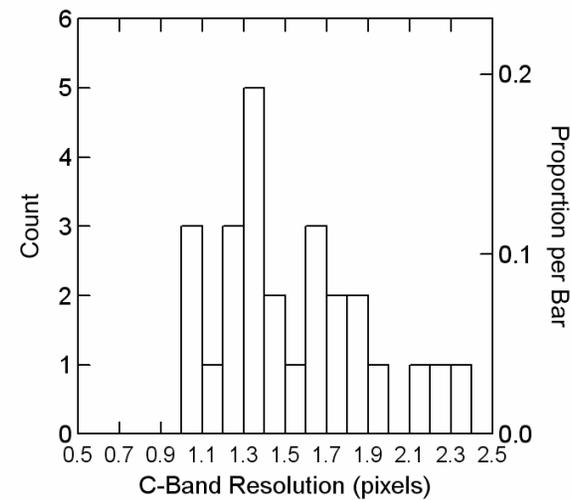
- Given the nonlinear nature of the woodlot/field boundaries, a nonlinear optimization approach was employed to solve for the unknown parameters in the Equation below. Specifically, the LMDIF function from the MINIPACK numerical library was used (Moré et al., 1980), which implements the Levenburg-Marquardt nonlinear least-squares optimization strategy.

$$\text{ramp}(x) = \begin{cases} -d, & x-c \leq -b/2 \\ (a/b)(x-c+b/2) - d, & -b/2 \leq x-c \leq b/2 \\ a-d, & b/2 \leq x-c \end{cases}$$



Resulting Horizontal Resolution Estimation

C-Band Resolution				X-Band Resolution			
Woodlot ID	Profile Length (pixels)	Estimated Resolution (pixels)	rms error (pixels)	Woodlot ID	Profile Length (pixels)	Estimated Resolution (pixels)	rms error (pixels)
INW1SS	15	1.2	1.58	INW1SE	11	1.4	1.32
ISW2SW	15	1.9	0.60	ISW2SW	13	1.3	1.43
ISW2SN	13	1.4	1.62	ISW2SN	11	1.3	1.68
ISW2SE	21	2.2	1.31	ISW2SE	11	1.7	1.69
ISW1SW	11	1.6	0.96	ISW2SS	15	1.3	1.67
ISW1SS	15	1.8	0.94	DSE3SE	13	1.6	1.61
DSE1SE	11	1.0	0.55	DSE2SW	11	1.4	1.54
DSE3SN	13	2.3	0.83	MNW1SE	13	1.8	1.21
DSE3SE	11	1.6	0.99	MNW4SE	13	1.5	1.34
DSE2SW	15	1.7	1.45	MNW8SW	13	0.9	1.70
INE2SN	17	1.0	1.51	MSW2SS	11	1.4	1.39
INE2SS	11	1.6	0.88	MNE4SW	11	1.2	1.66
MNW1SN	21	1.3	1.64	MNE2SE	13	1.7	1.35
MNW1SE	15	1.7	1.35				
MNW1SS	21	1.5	1.31				
MNW6SW	13	1.4	1.54				
MNW5SN	11	1.2	0.77				
MNW7SS	17	1.3	1.66				
MNW9SW	15	1.3	1.13				
MSW1SE	17	2.1	1.26				
MSW2SN	19	1.2	1.57				
MSW2SS	15	1.3	0.75				
MNE5SW	17	1.8	1.16				
MNE5SE	15	1.1	1.69				
MNE2SN	13	1.3	0.98				
MNE2SS	13	1.0	1.55				
Mean	15	1.5	1.21		12	1.4	1.51



Conclusions

- The “vegetation noise” is a unprecedented globally available “vegetation signal” in both C- and X-Band
 - Sample averaging is critical for height retrieval
- Mast motion error can be detected via “bald surfaces” and effects can be mitigated or reduced in comparison with a “bald-earth” DEM
- NED is a good “bald-Earth” reference DEM
 - To be used with caution
 - We need an accuracy/quality map for NED ...
 - Please eliminate the 1/2 pixel shift on the seamless server
- To estimate noise amount in the data, we need the number of data takes per pixel
 - We need that “Data Take” Layer!!!



Conclusions

- 1 Arcsec resolution preferred to allow for “segment-based” averaging and noise reduction
 - Capability to segment data around homogenous forest stands is reduced through smaller resolution
- 3 Arcsec data should be generated through sample averaging, not thinning
 - Reduces height noise in vegetation (and everything else ...)
- Please see Poster on the “National Biomass and Carbon Dataset 2000”
 - NASA funded project combining SRTM, NED, NLCD2001 and FIA Data

Thank You!



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(after July)