

*Landsat Science Team Meeting, Boise, Idaho, June 15-17, 2010*

## **Landsat Science Team PI Report**

# **Enhancing Landsat Data Products Using Data Fusion Approach**

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**NASA GSFC and ERT Inc.**

# Topics

- Fusing NDVI for NOAA AVHRR and Landsat MSS/TM
  - Normalize NDVI between AVHRR and Landsat
  - Fuse NDVI using StarFM approach
  - Produce annual phenology metrics from Landsat NDVI time series
- Examining Landsat within-scene BRDF effects
  - BRDF samples from typical surface types
  - Landsat scene simulation

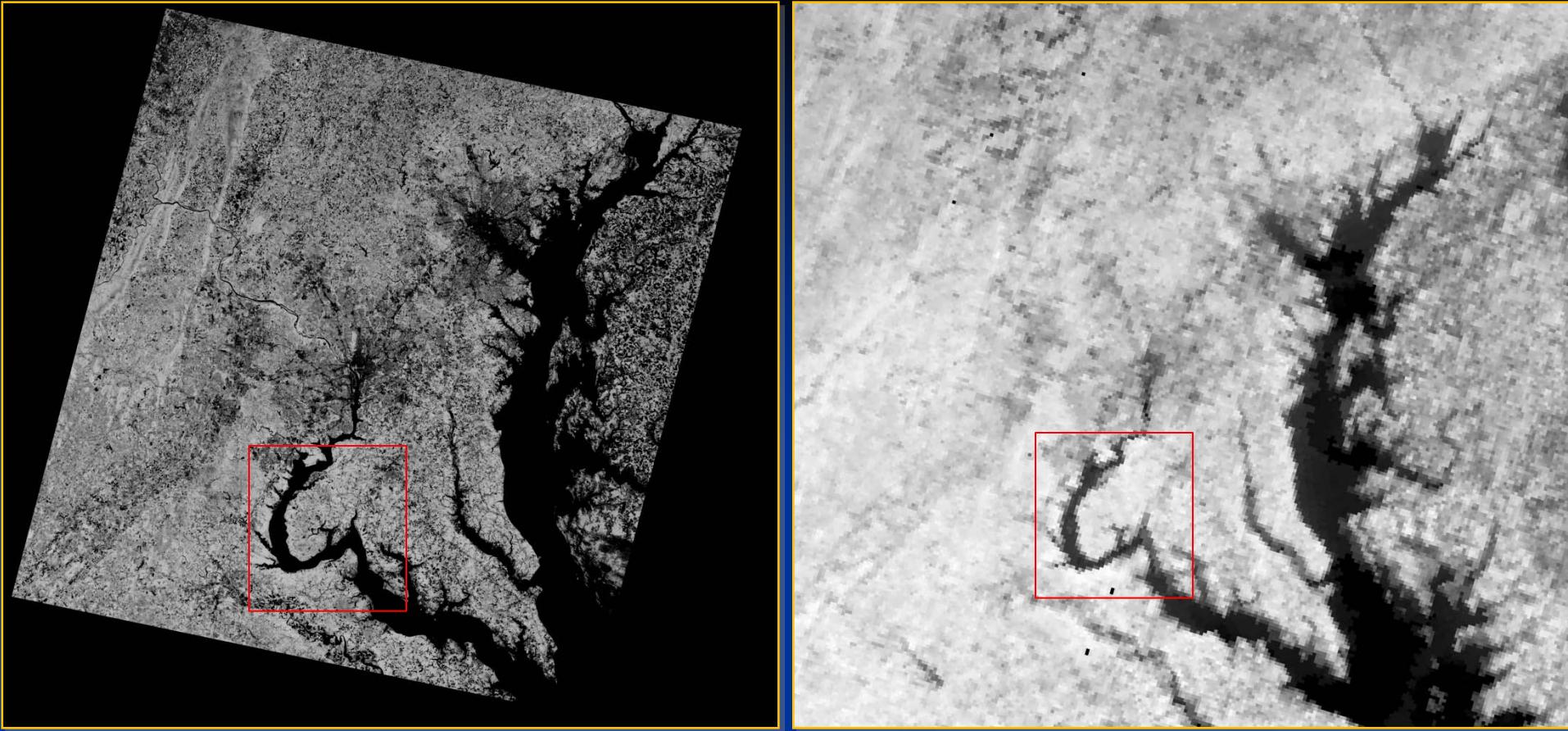
# Part I. Fusing NDVI from NOAA AVHRR and Landsat TM/MSS

- Previous data fusion efforts were focused on fusing MODIS and Landsat reflectance data
- The objective for this case study is to extend our data fusion approach to fuse historical NDVI data between AVHRR and Landsat MSS/TM

	visible/red band ( $\mu\text{m}$ )	NIR band ( $\mu\text{m}$ )
AVHRR	0.58-0.68	0.73-1.05
MSS	0.60-0.70	0.70-0.80
TM	0.63-0.69	0.76-0.90

# Data Sets

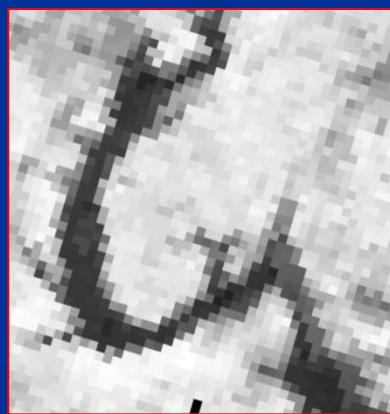
- AVHRR NDVI composites from USGS EROS
  - bi-weekly maximum NDVI composites for 1990
  - LAC 1km spatial resolution from NOAA-11
  - conterminous United States and Alaska
- Landsat MSS and TM (WRS-2 p15r33, D.C. area)
  - MSS: 1990-128 (May 8) – pair 1
  - TM: 1990-224 (Aug 12) – pair 2
  - 1990-288 (Oct 15) – pair 3
  - 1990-320 (Nov 16) – pair 4



## NDVI PAIR 1

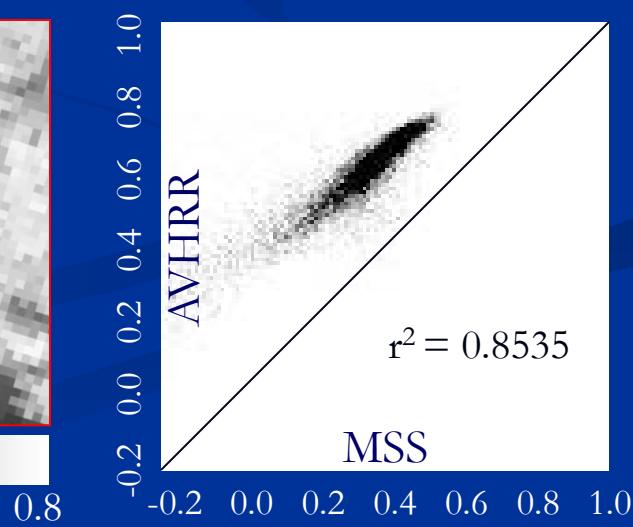
MSS: 128  
(5/8)

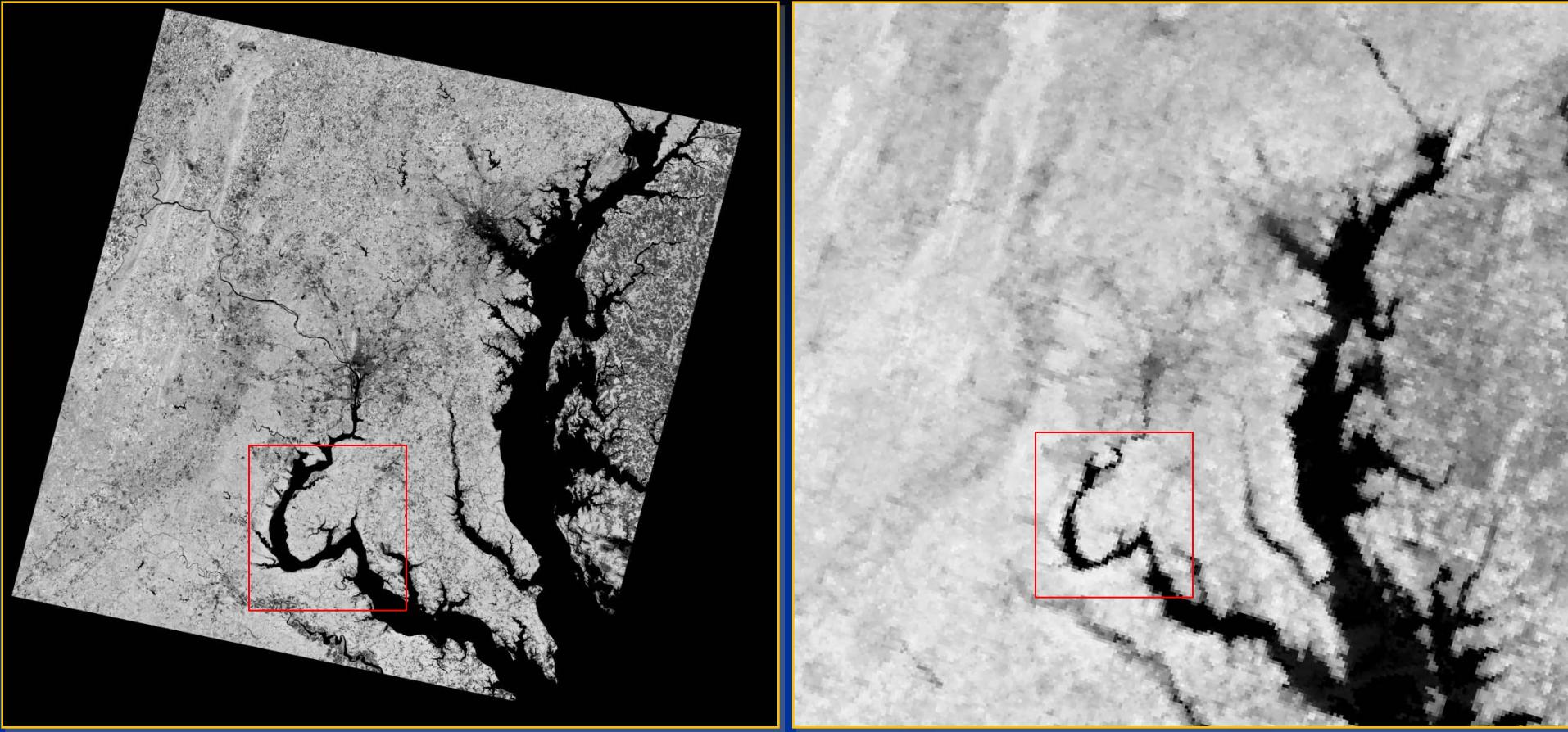
AVHRR: 117-130  
(4/27 – 5/10)



0.0 0.2 0.4 0.6 0.8

-0.2 0.0 0.2 0.4 0.6 0.8 1.0

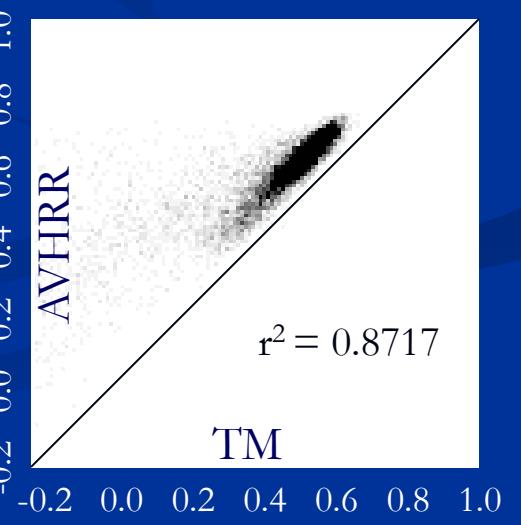
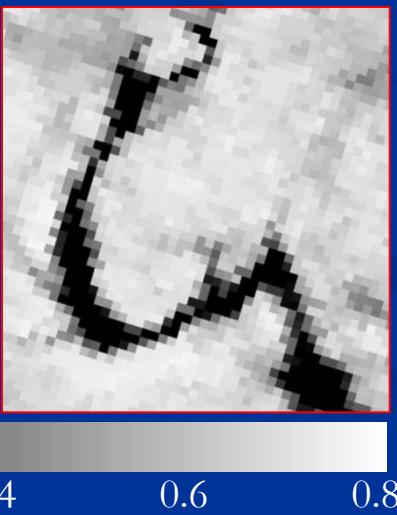
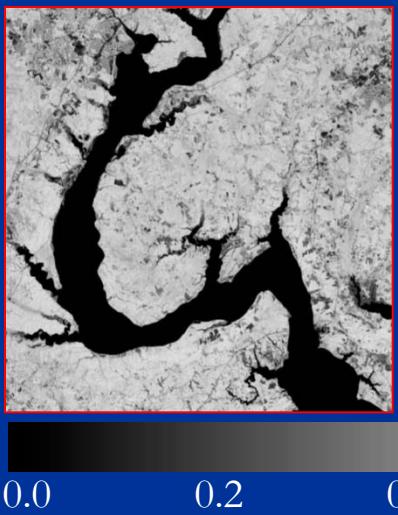




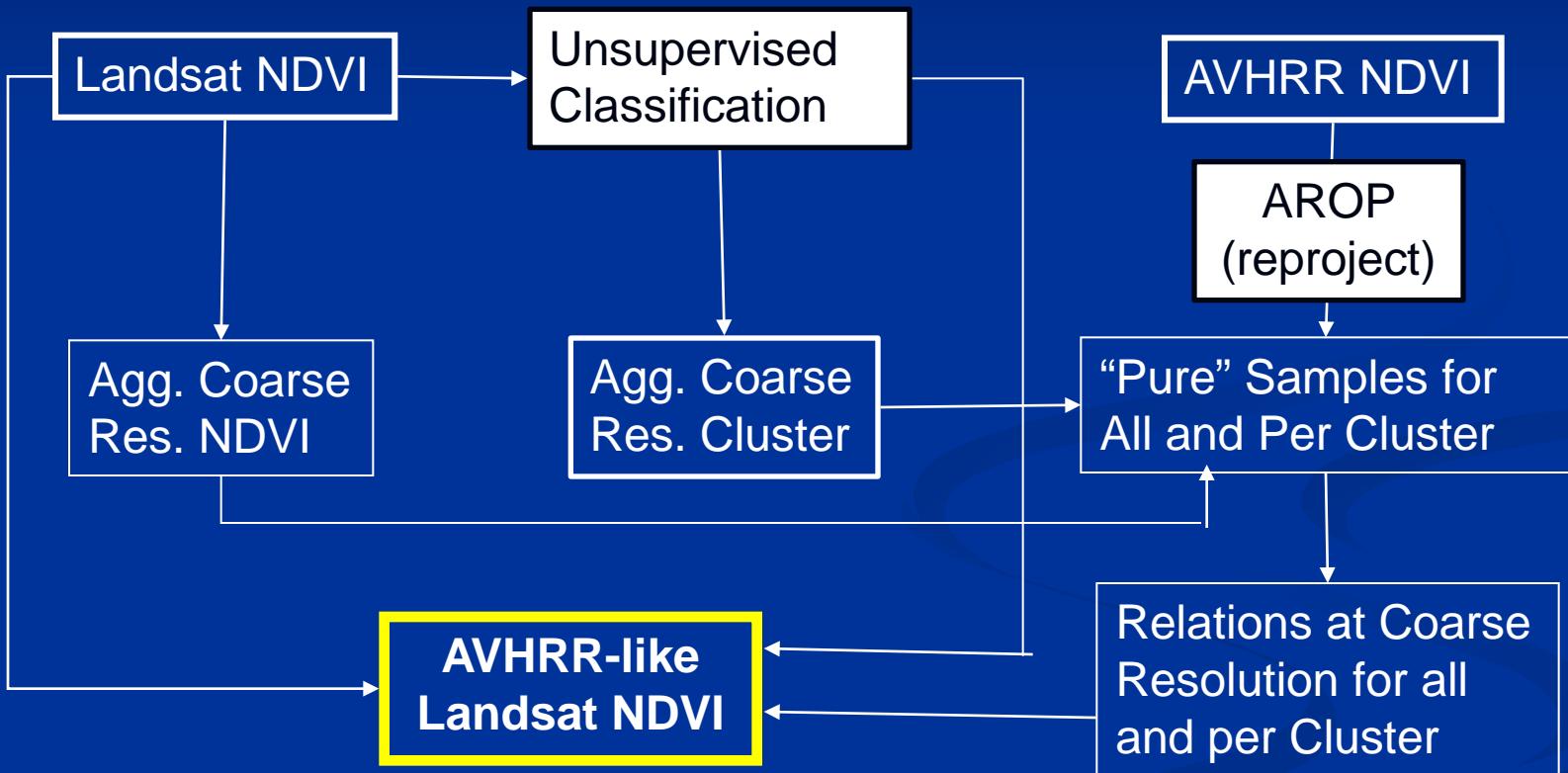
## NDVI PAIR 3

TM: 288  
(10/15)

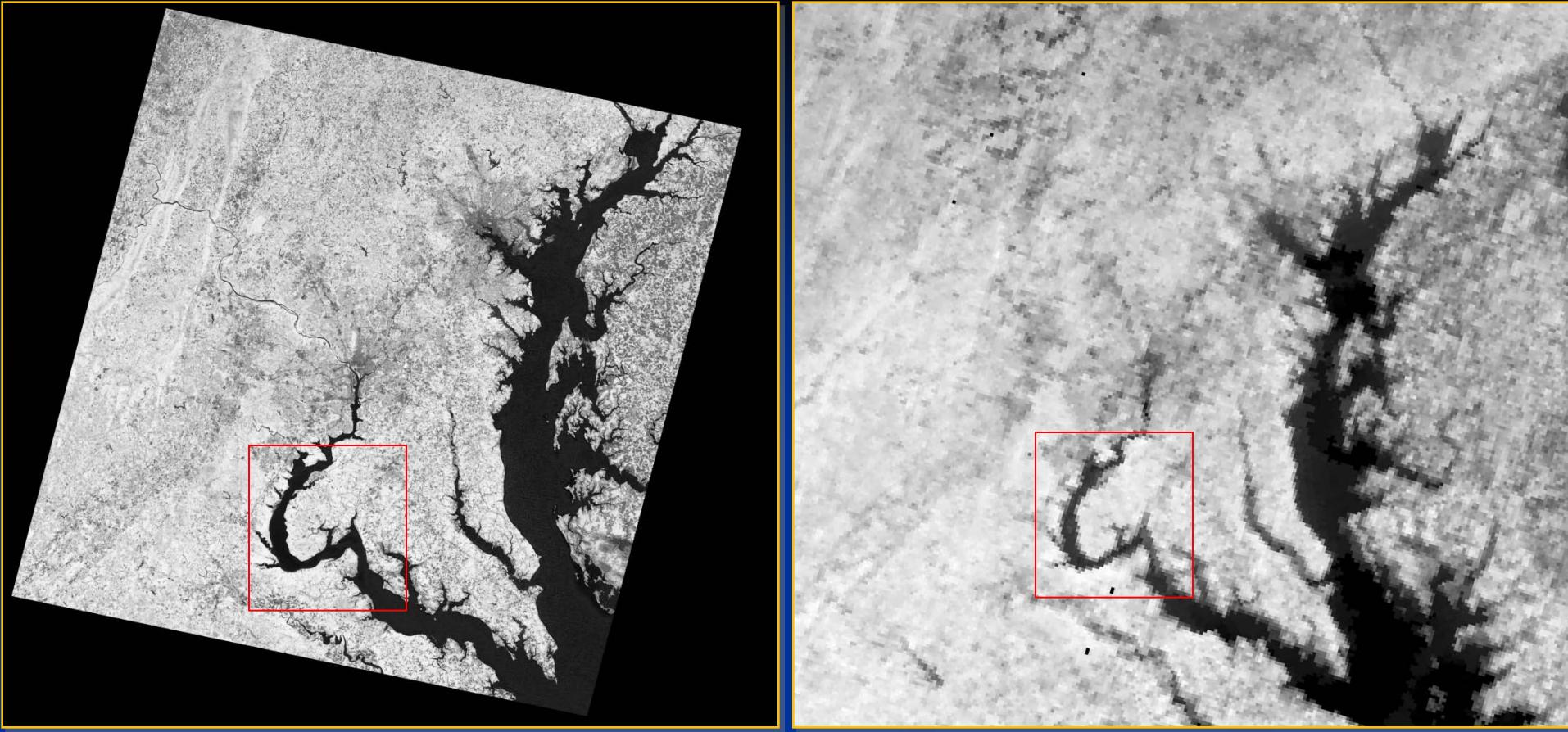
AVHRR: 285-298  
(10/12 – 10/25)



# Landsat and AVHRR Normalization



Gao, F., J. Masek, R. Wolfe, and C. Huang, 2010, Building consistent medium resolution satellite data set using MODerate resolution Imaging Spectroradiometer products as reference, Journal of Applied Remote Sensing, Vol. 4, 043526, doi: 10.1117/1.3430002.



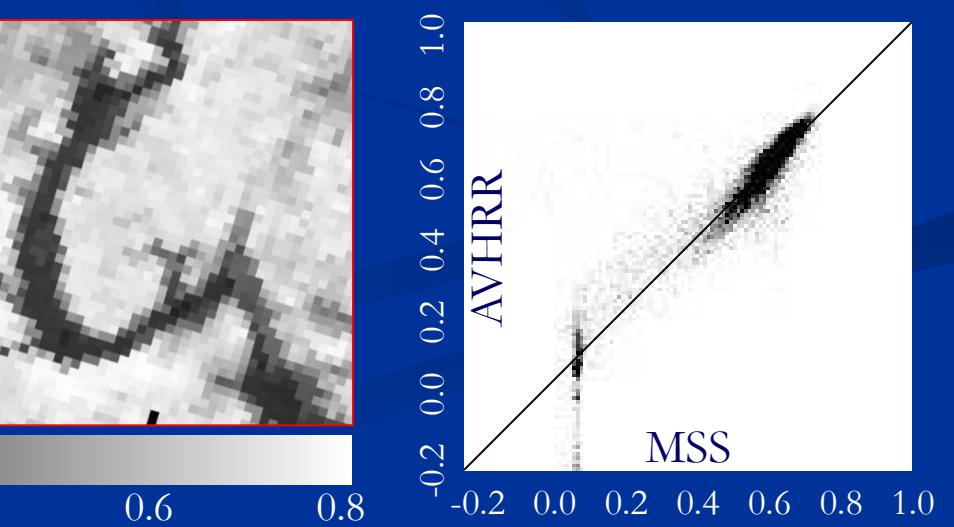
## Adjusted NDVI Pair 1

MSS: 128(5/8)

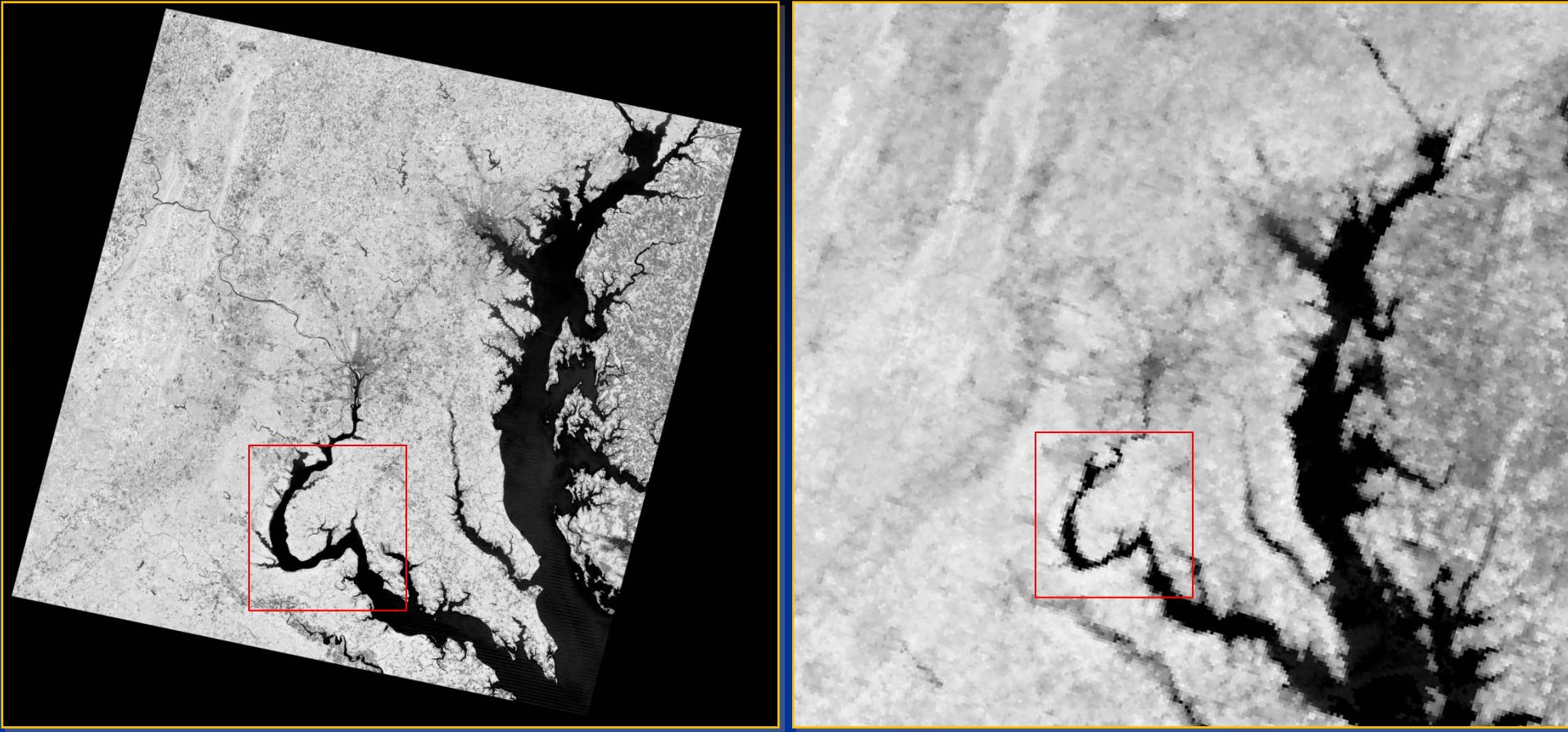
AVHRR: 117-130  
(4/27 – 5/10)



0.0 0.2 0.4 0.6 0.8



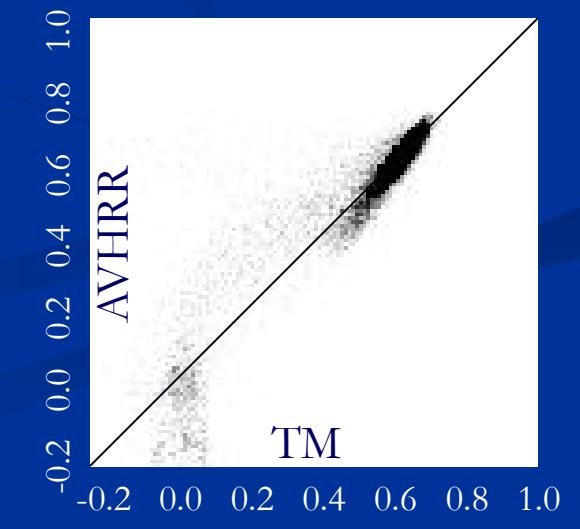
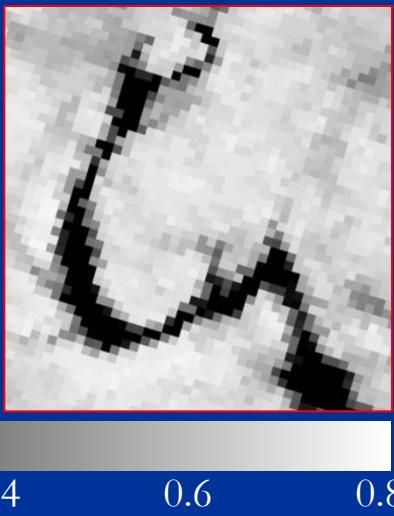
-0.2 0.0 0.2 0.4 0.6 0.8 1.0



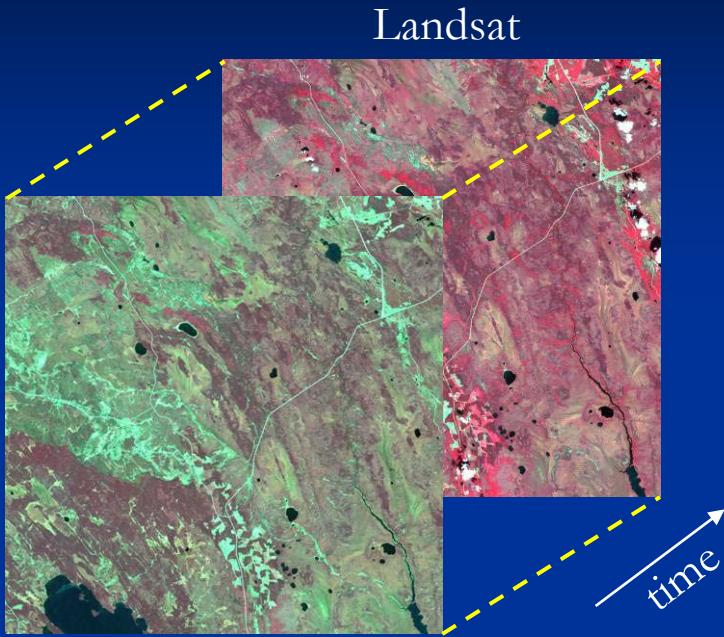
**Adjusted NDVI**  
**Pair 3**

TM: 288 (10/15)

AVHRR: 285-298  
(10/12 – 10/25)



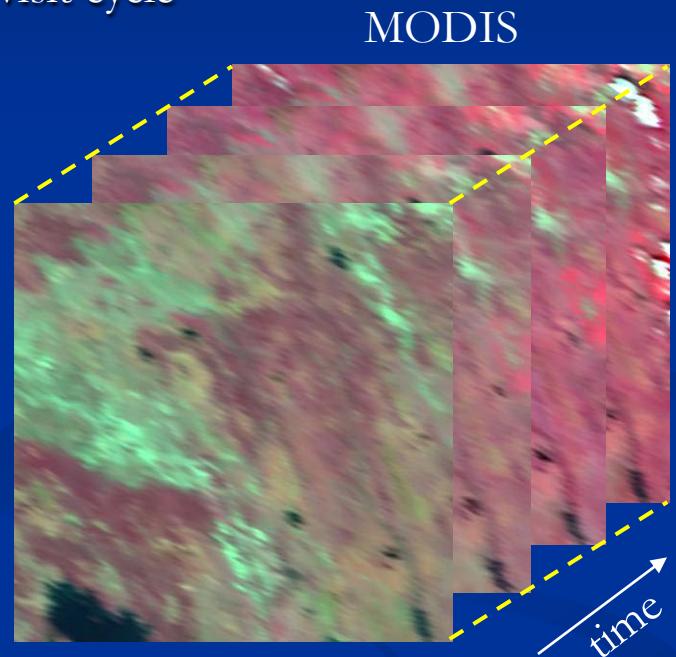
# Spatial and Temporal Data Fusion



Landsat

■ MODIS

- one or two revisit per day
- 250m & 500m spatial resolution



MODIS

- Landsat
  - 30m spatial resolution
  - 16-day revisit cycle

Gao et al., TGRS 2006; Roy et al., RSE 2008; Hilker et al., RSE 2009

Zhu, X., J. Chen, F. Gao, and J. Masek, An Enhanced Spatial and Temporal Adaptive Reflectance Fusion Model for Complex Heterogeneous Regions, RSE, 2010, accepted in press.

**Objective - combine the spatial resolution of Landsat with the temporal frequency of coarse-resolution MODIS.**

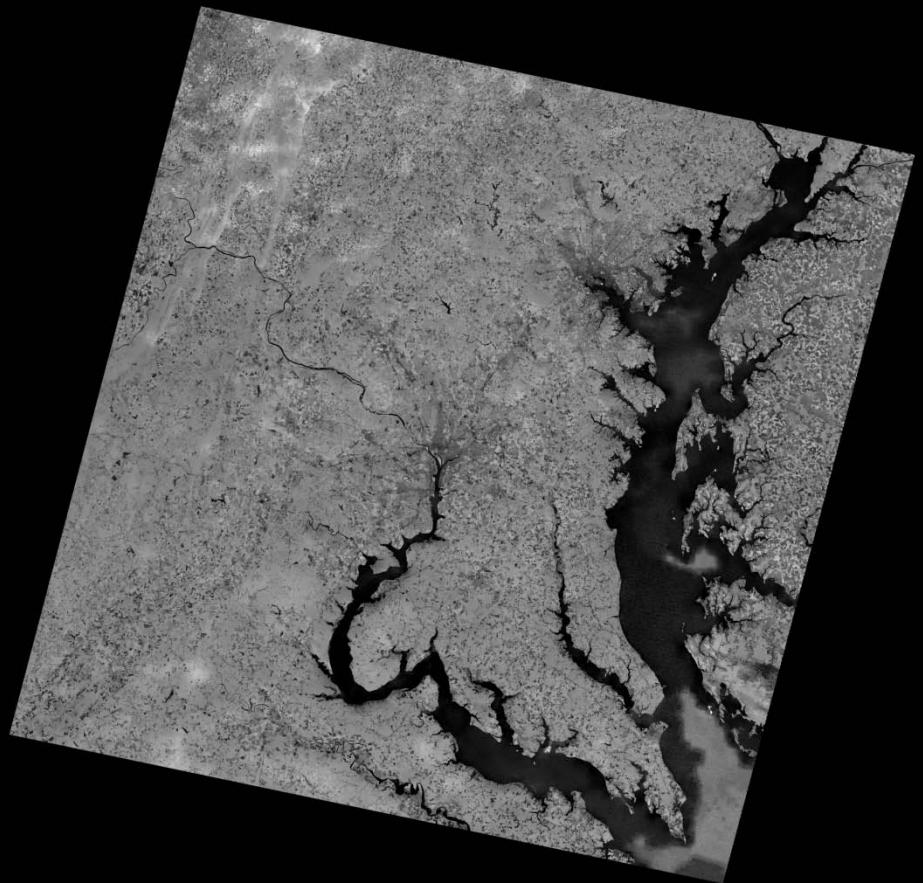
# StarFM Fusion Plan

Index	AVHRR B. Date	AVHRR E. Date	Landsat Acquisition Date	Input Pairs	Goal
1	1990-003	16		128	prediction
2	17	30		128	prediction
3	31	44		128	prediction
4	45	58		128	prediction
5	61	74		128	prediction
6	75	88		128	prediction
7	89	102		128	prediction
8	103	116		128	prediction
9	117	130	128 (MSS)	224	validation
10	131	144		128	prediction
11	145	158		128	prediction
12	159	172		128	prediction
13	173	186		224	prediction
14	187	200		224	prediction
15	201	214		224	prediction
16	215	228	224 (TM)	128, 288	validation
17	229	242		224	prediction
18	243	256		224	prediction
19	257	270		224	prediction
20	271	284		288	prediction
21	285	298	288 (TM)	224	validation
22	299	312		288	prediction
23	313	326	320 (TM)	288	validation
24	327	340		320	prediction
25	341	354		320	prediction
26	355	1991-003		320	prediction

# Fused NDVI for 1990 003-016



Original AVHRR NDVI



Predicted Landsat NDVI



0.0

0.1

0.2

0.3

0.4

0.5

0.6

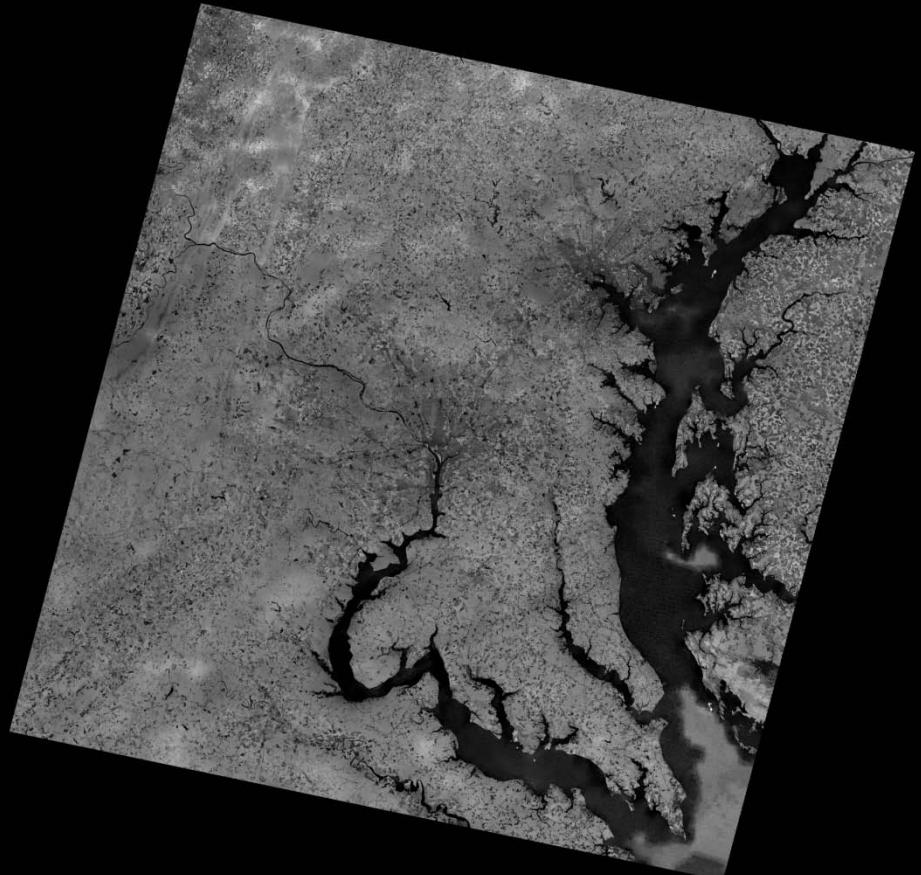
0.7

0.8

# Fused NDVI for 1990 017-030



Original AVHRR NDVI



Predicted Landsat NDVI

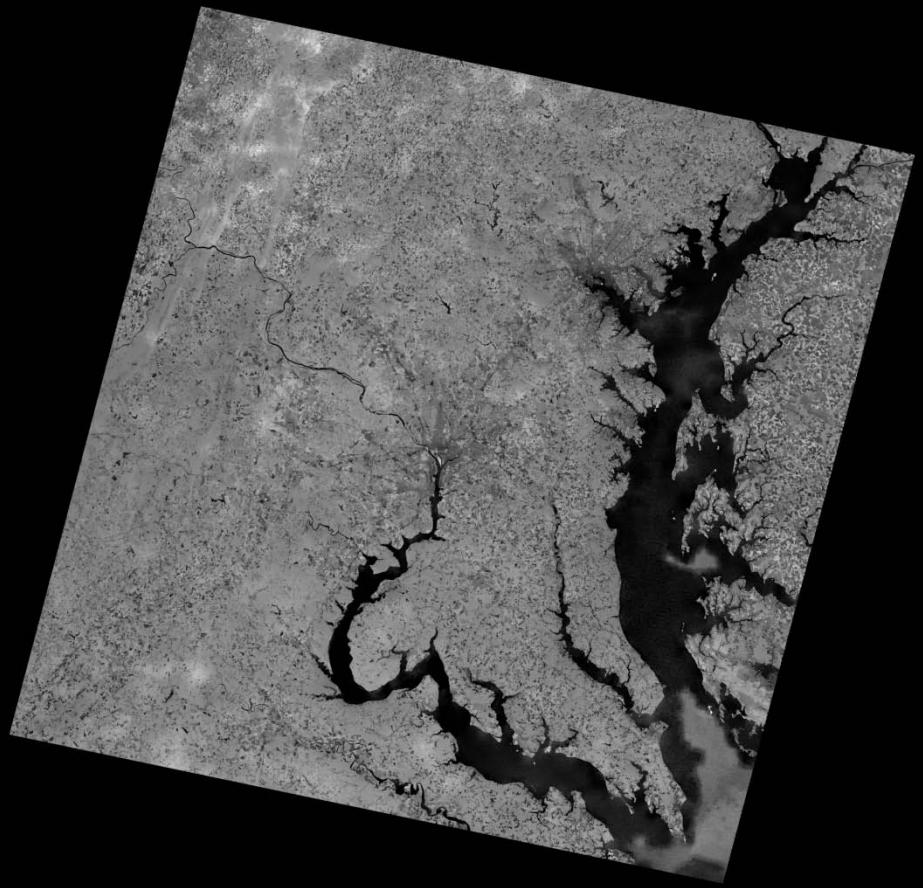


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 031-044



Original AVHRR NDVI



Predicted Landsat NDVI

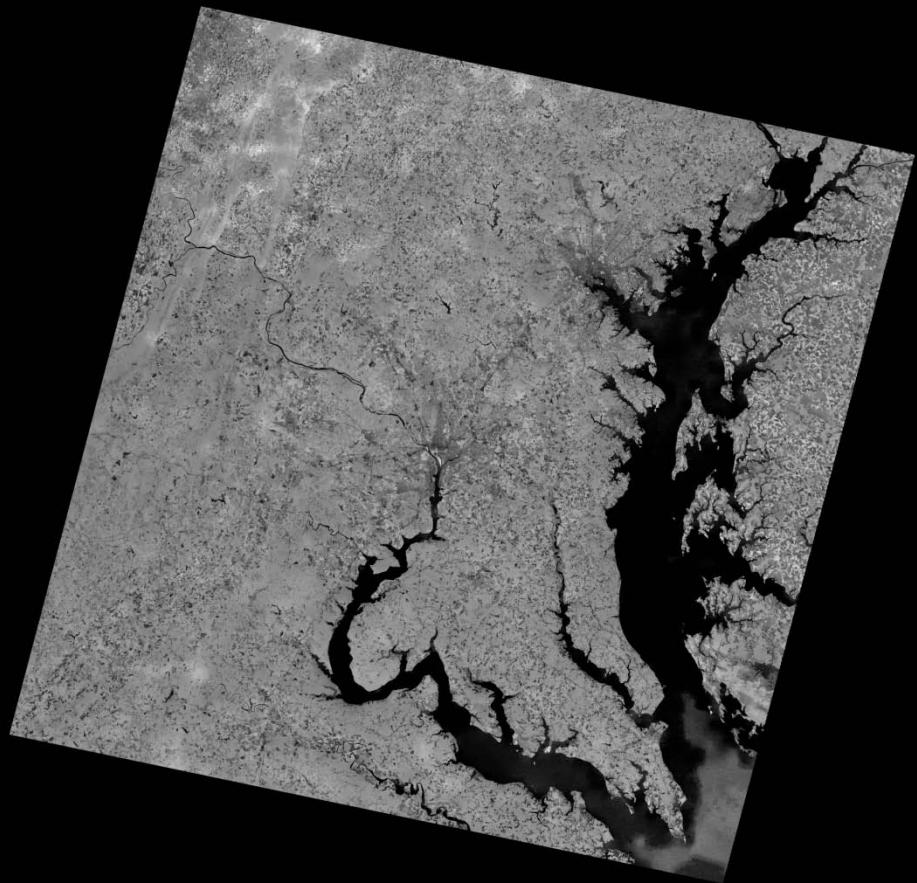


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 045-058



Original AVHRR NDVI

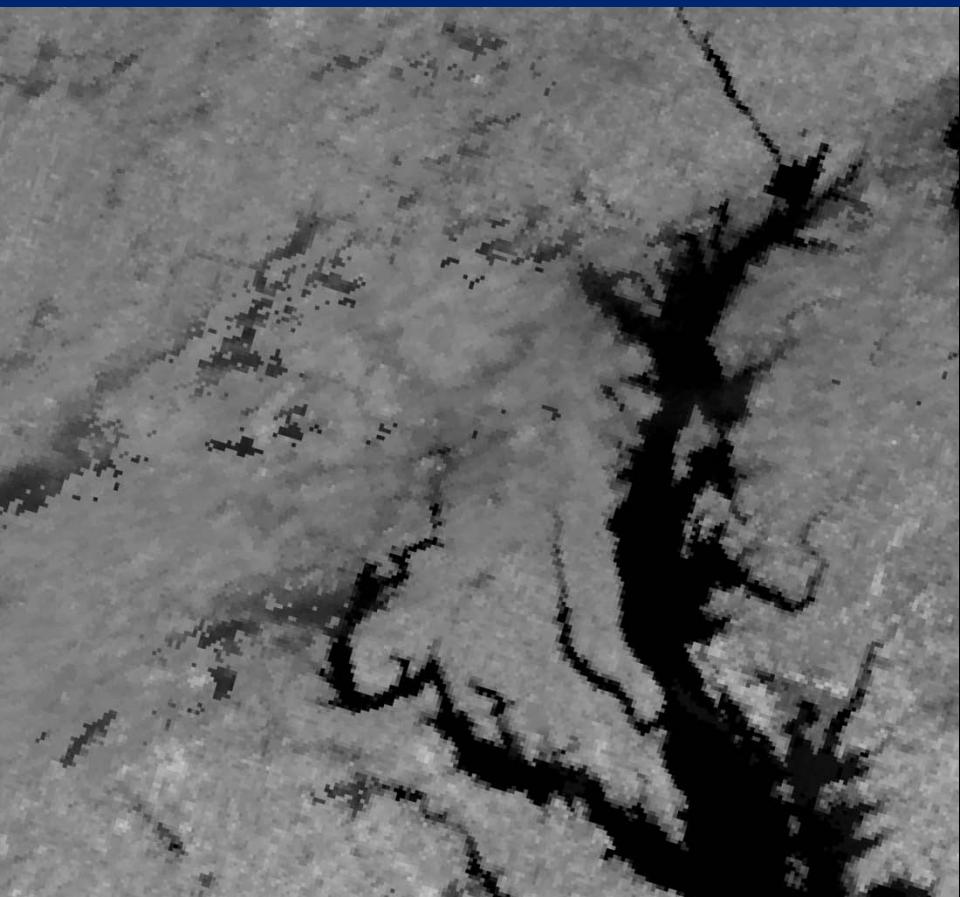


Predicted Landsat NDVI

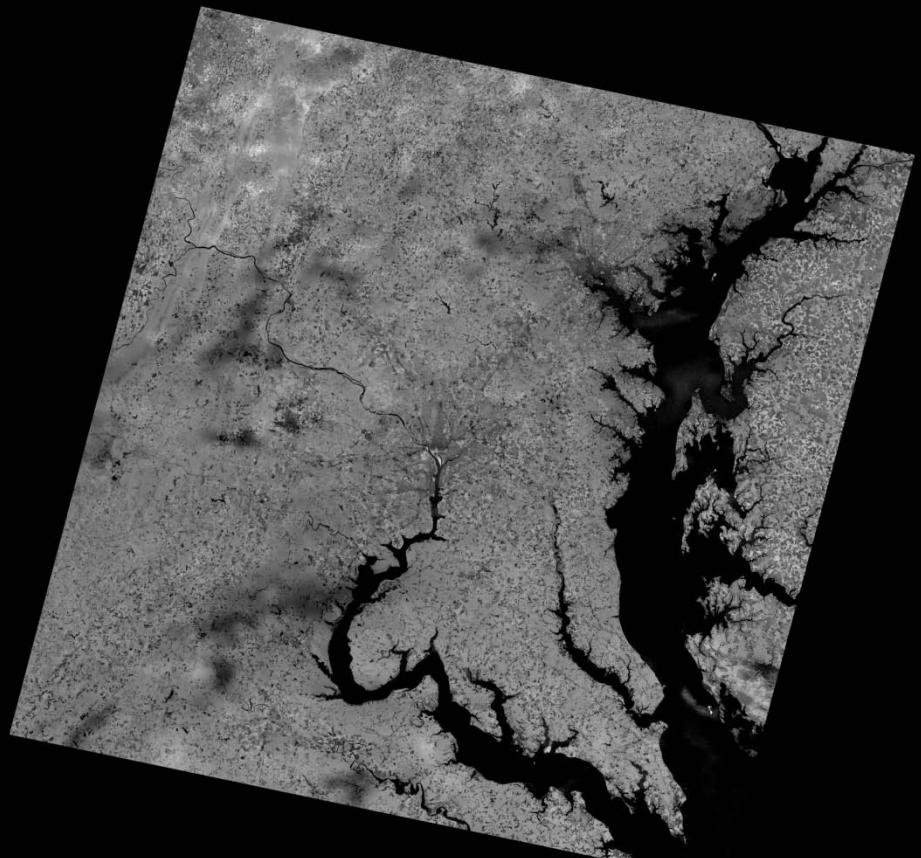


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 061-074



Original AVHRR NDVI



Predicted Landsat NDVI



0.0

0.1

0.2

0.3

0.4

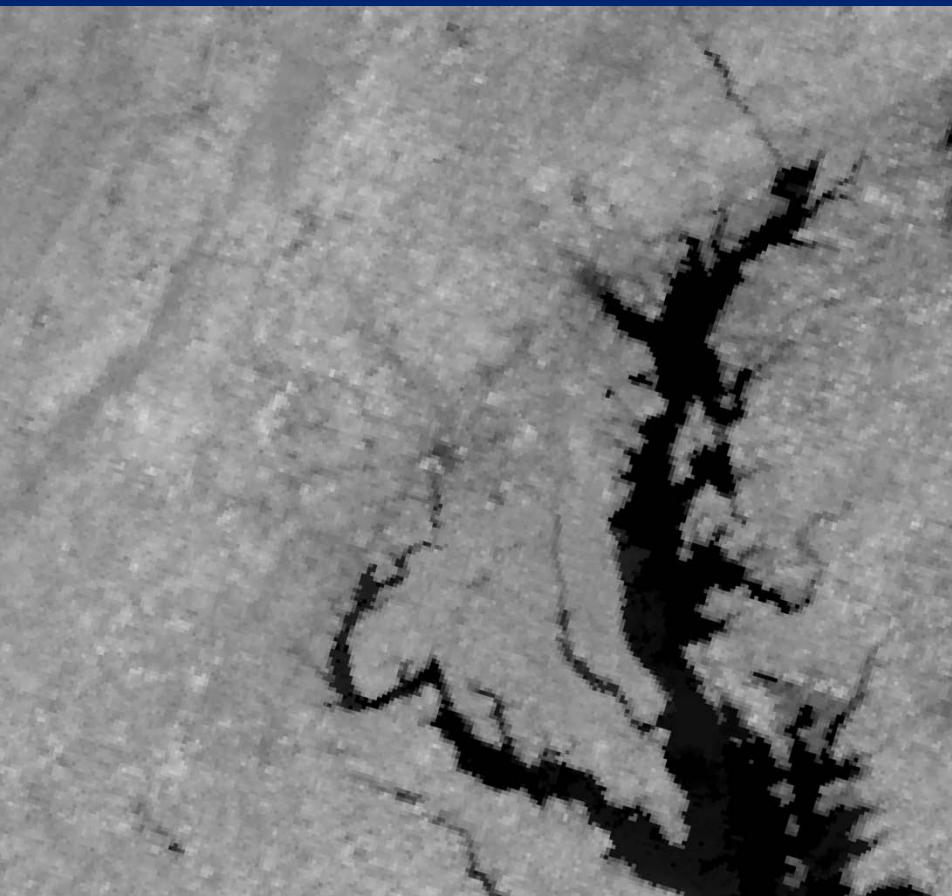
0.5

0.6

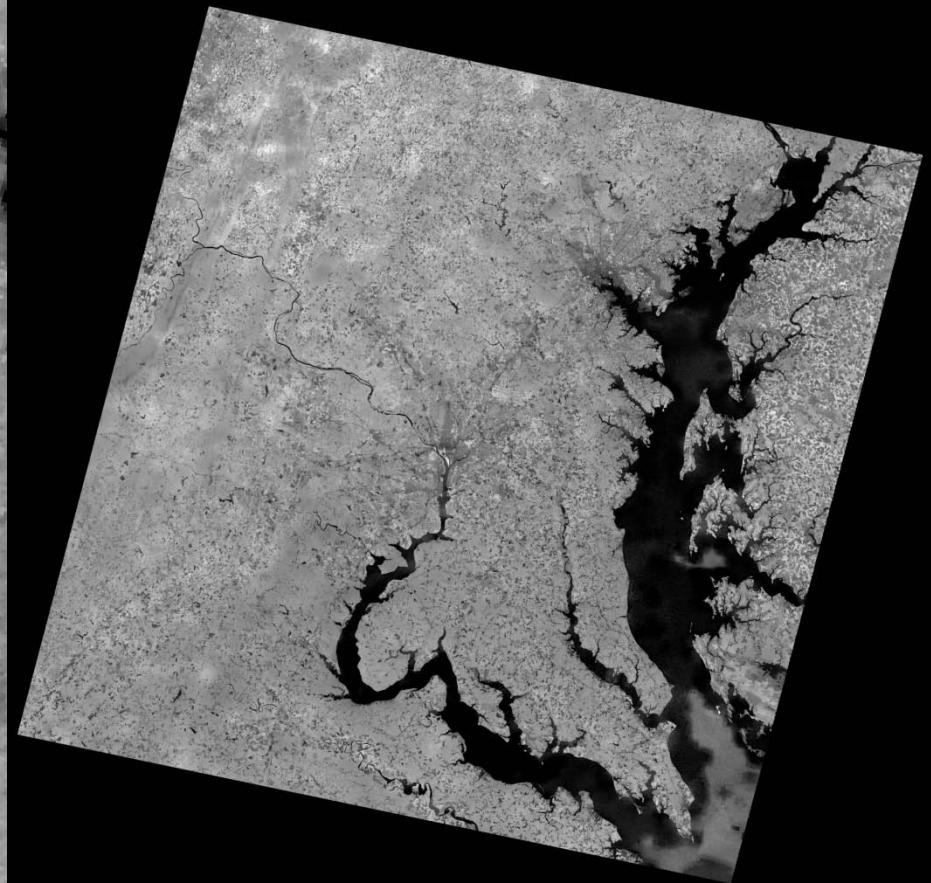
0.7

0.8

# Fused NDVI for 1990 075-088



Original AVHRR NDVI

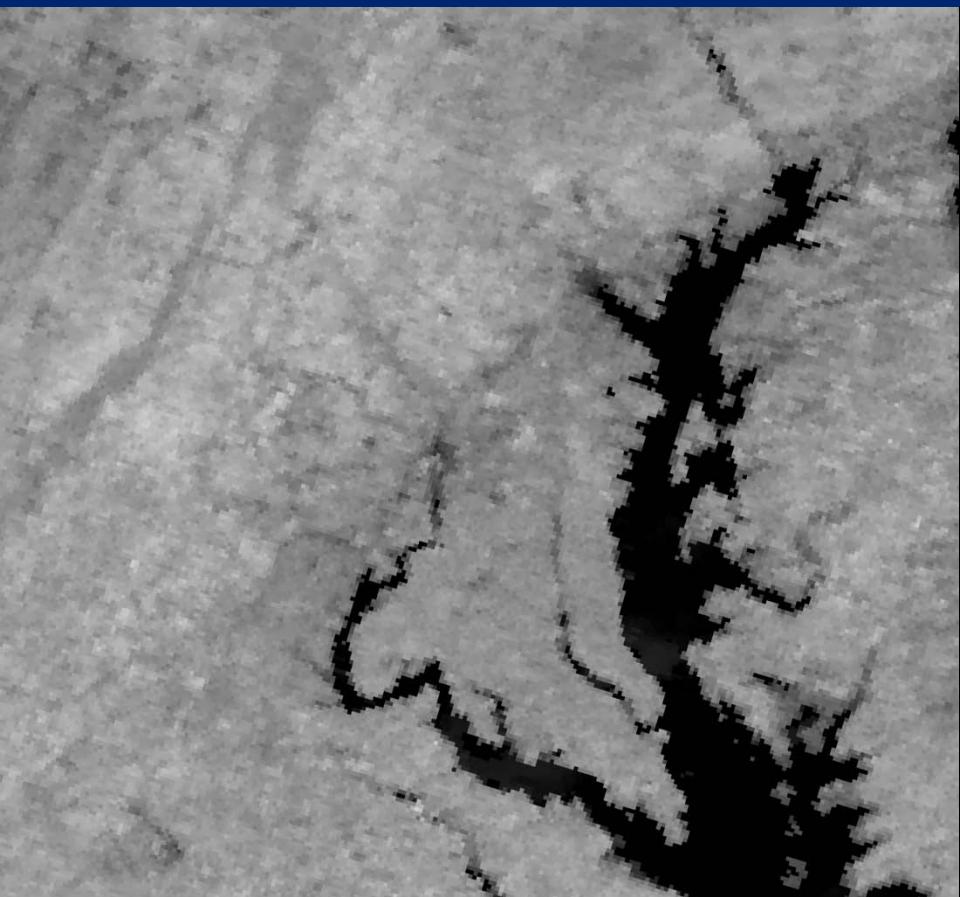


Predicted Landsat NDVI

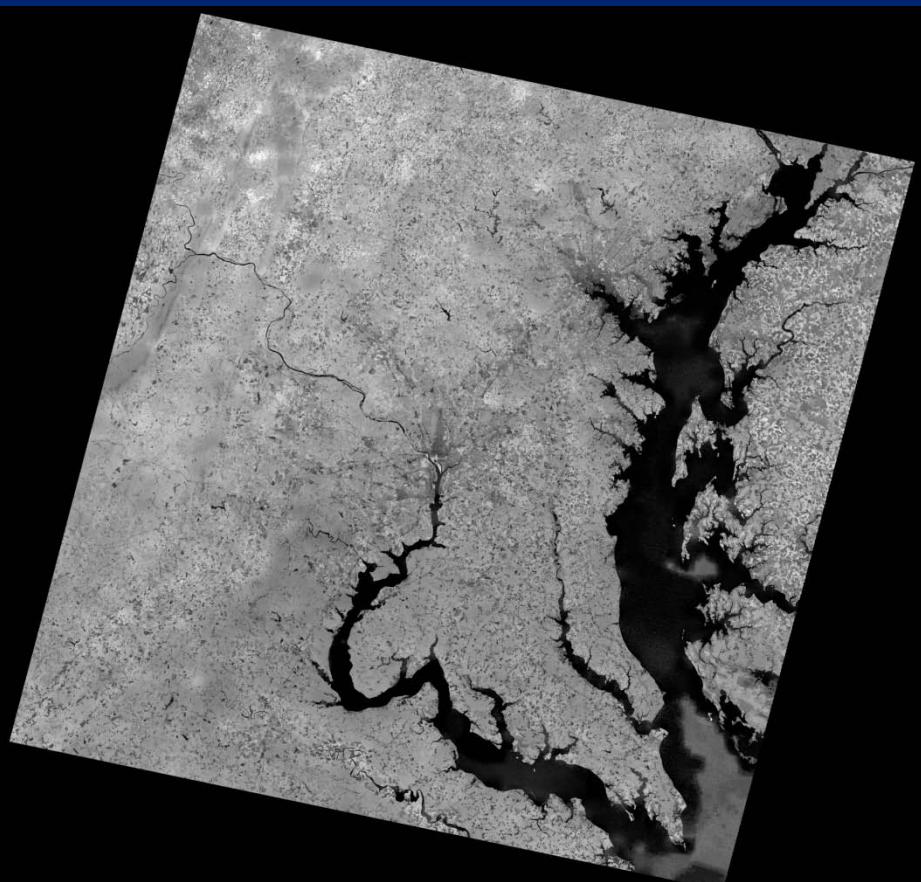


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 089-102



Original AVHRR NDVI

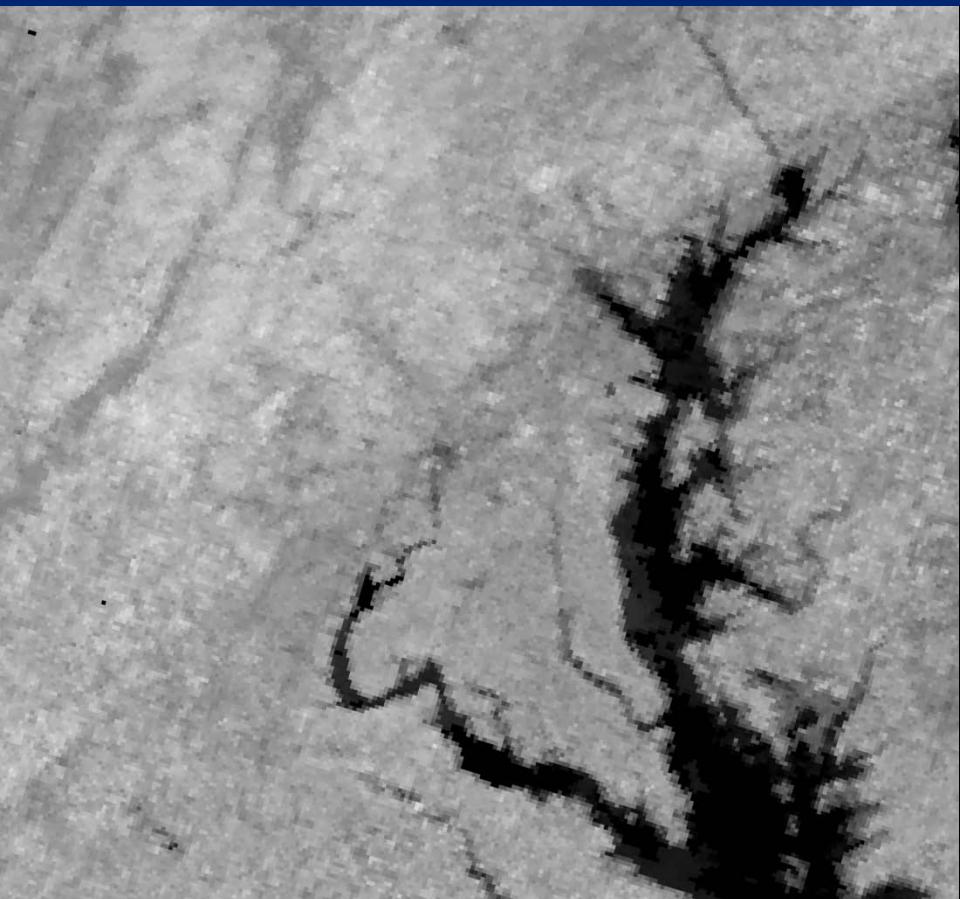


Predicted Landsat NDVI

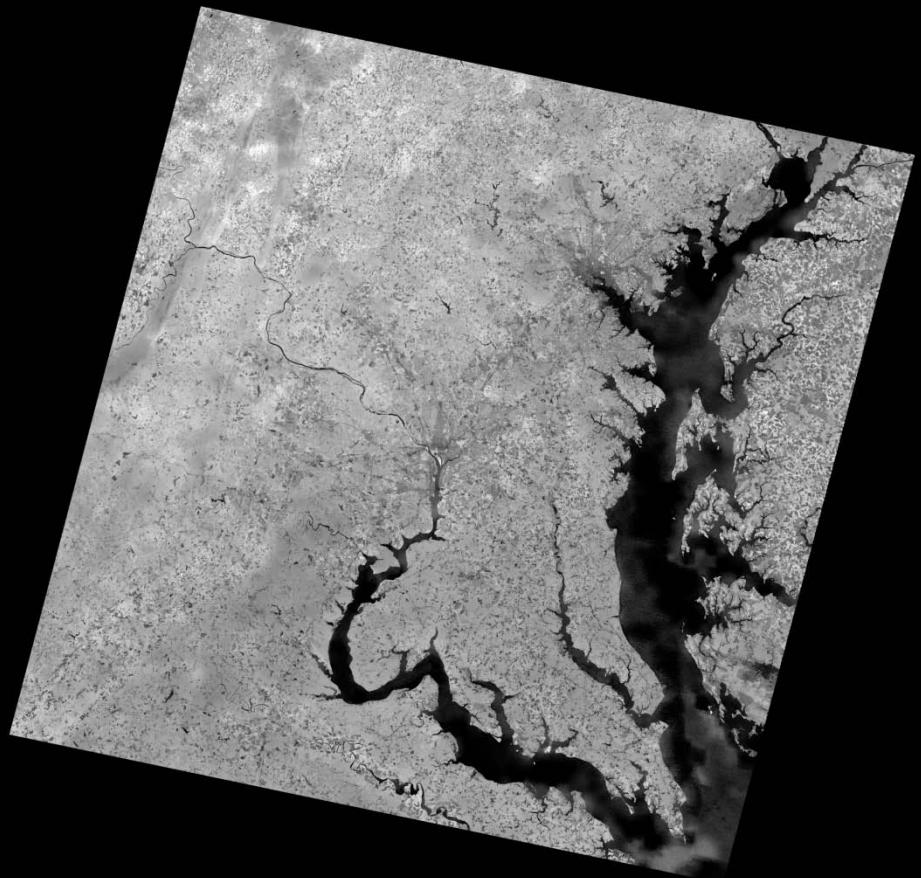


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 103-116



Original AVHRR NDVI



Predicted Landsat NDVI

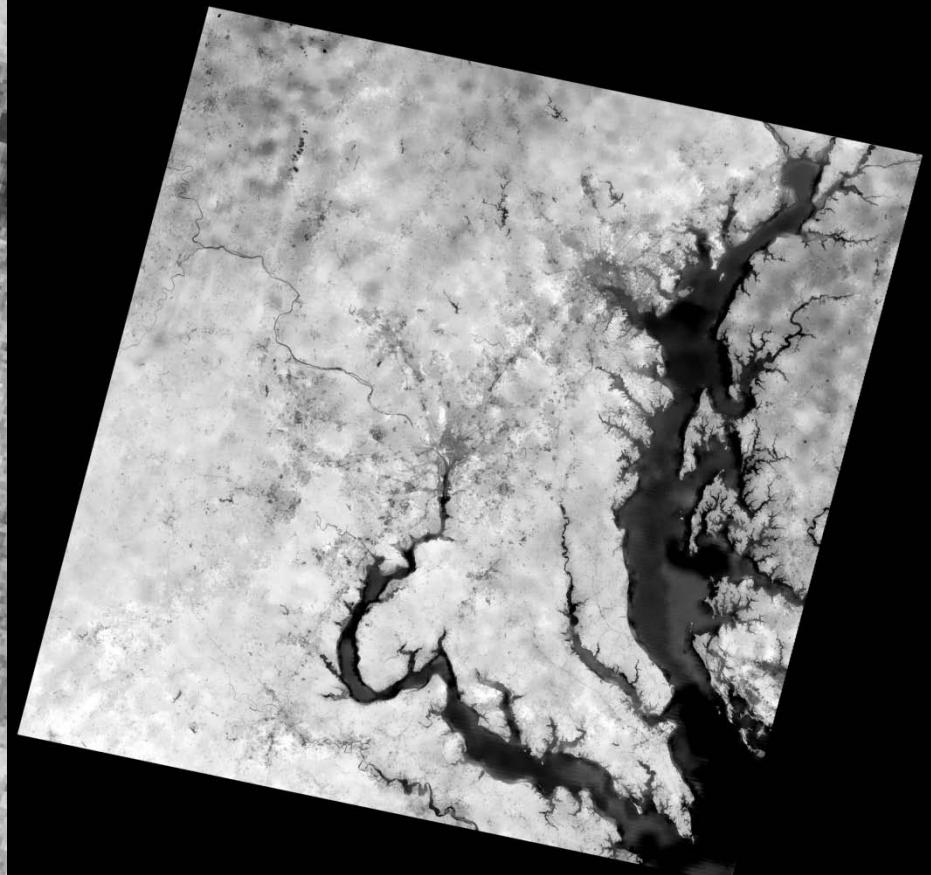


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 117-130



Original AVHRR NDVI

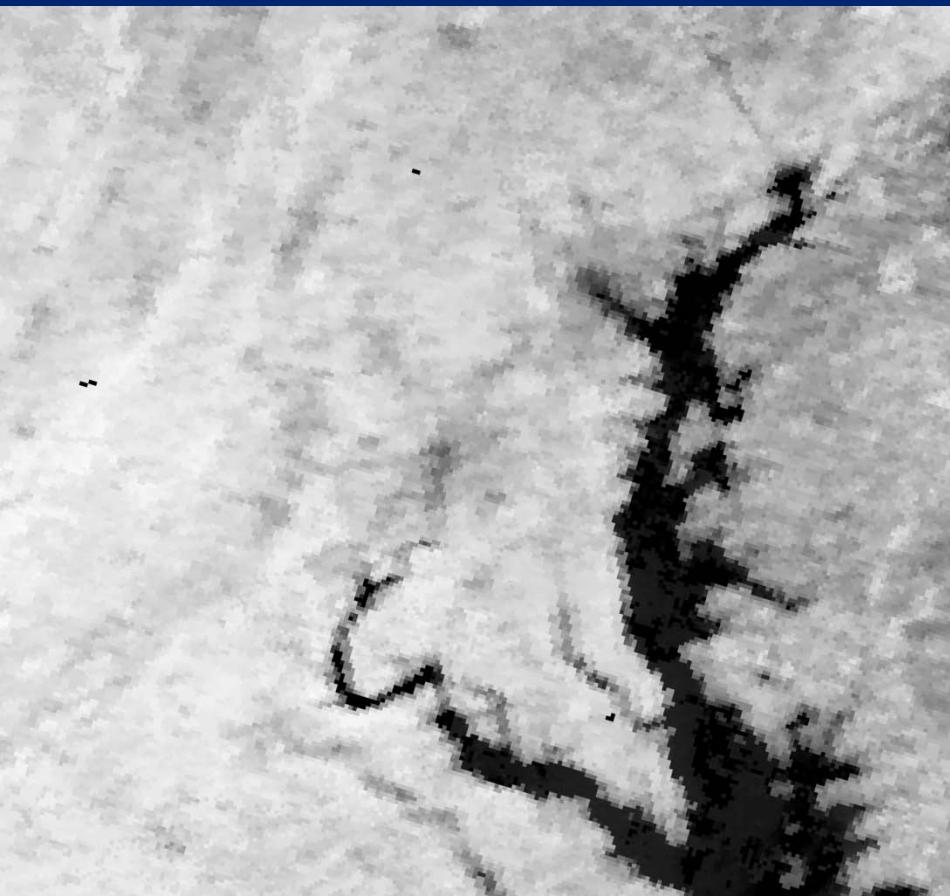


Predicted Landsat NDVI

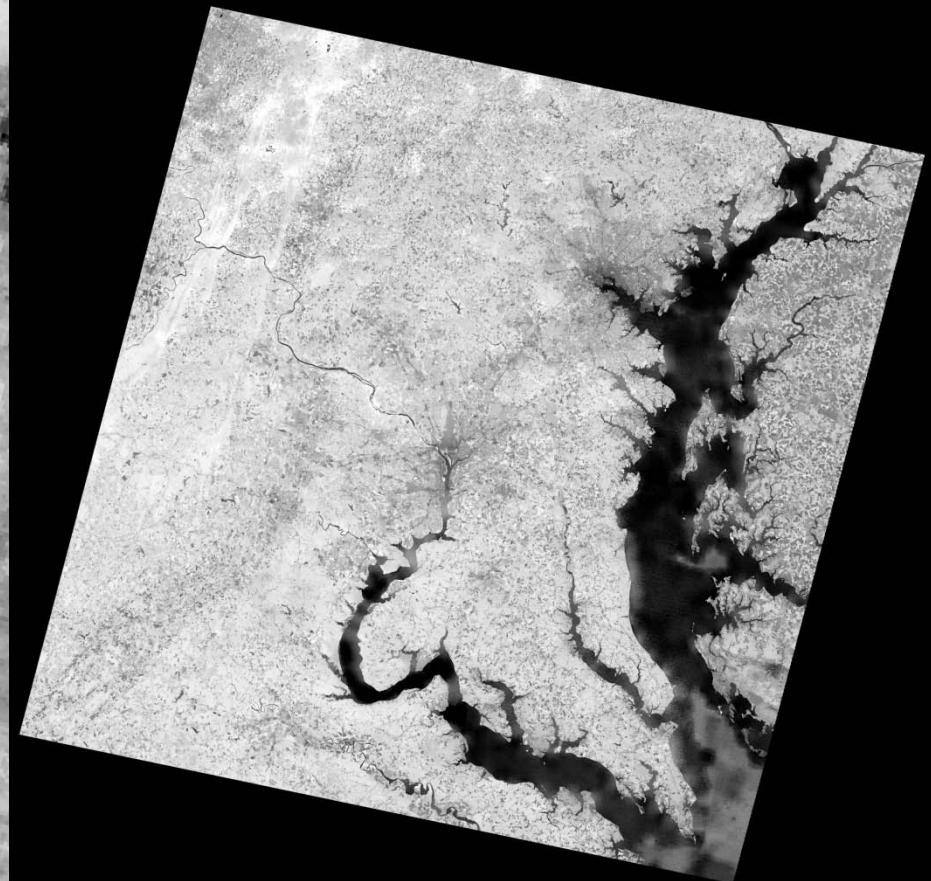


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 131-144



Original AVHRR NDVI



Predicted Landsat NDVI

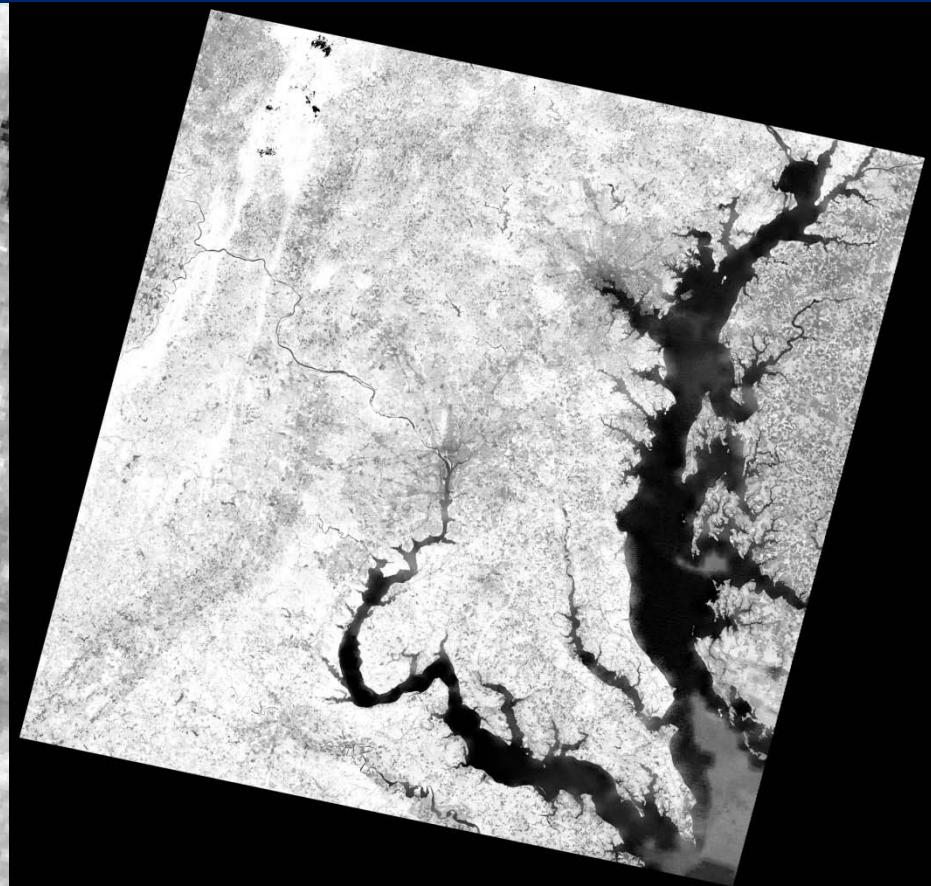


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 145-158



Original AVHRR NDVI



Predicted Landsat NDVI

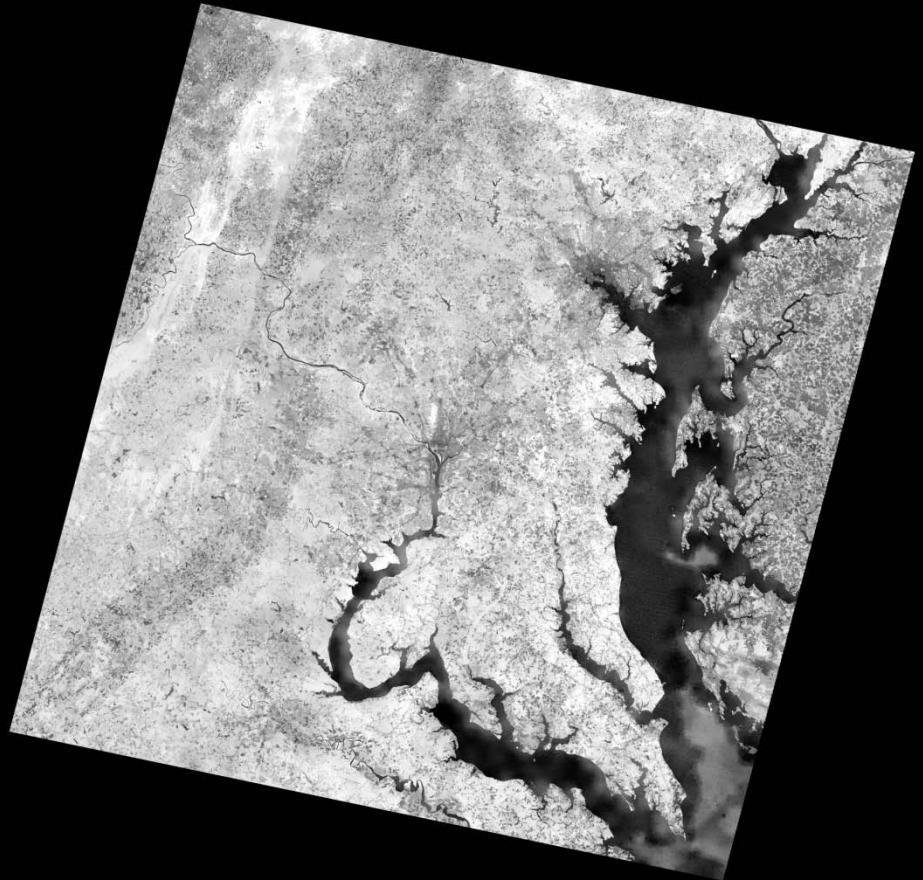


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 159-172



Original AVHRR NDVI

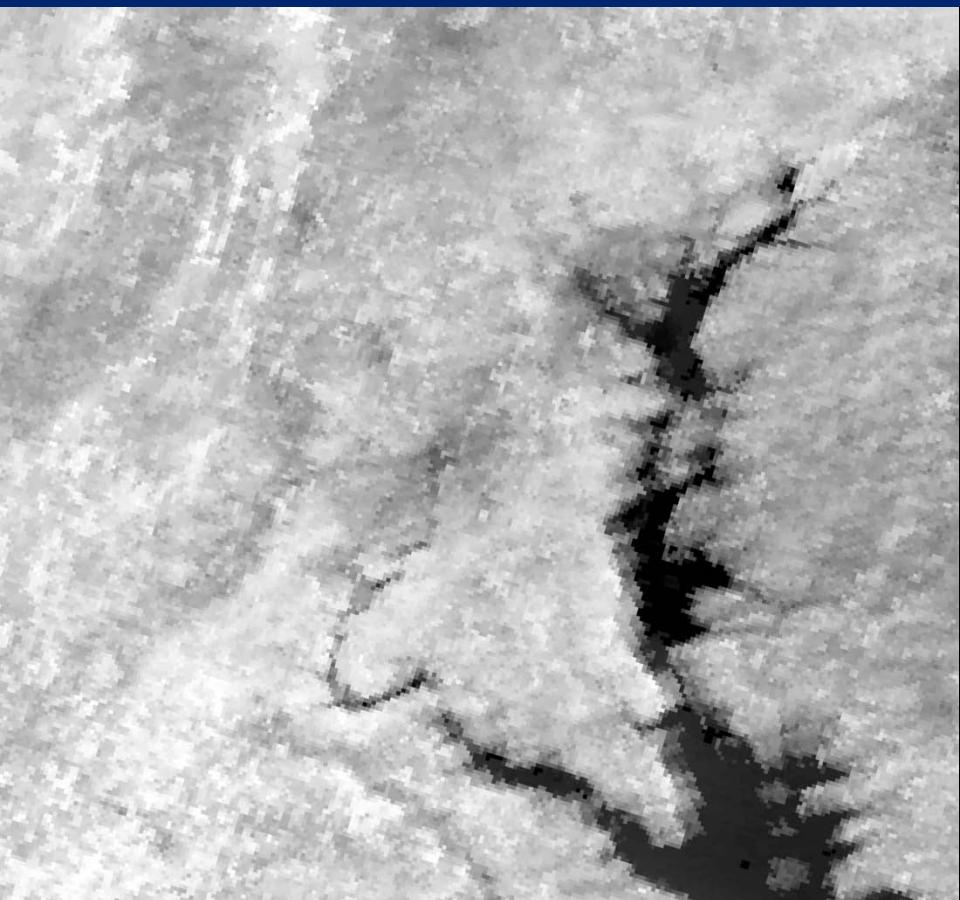


Predicted Landsat NDVI

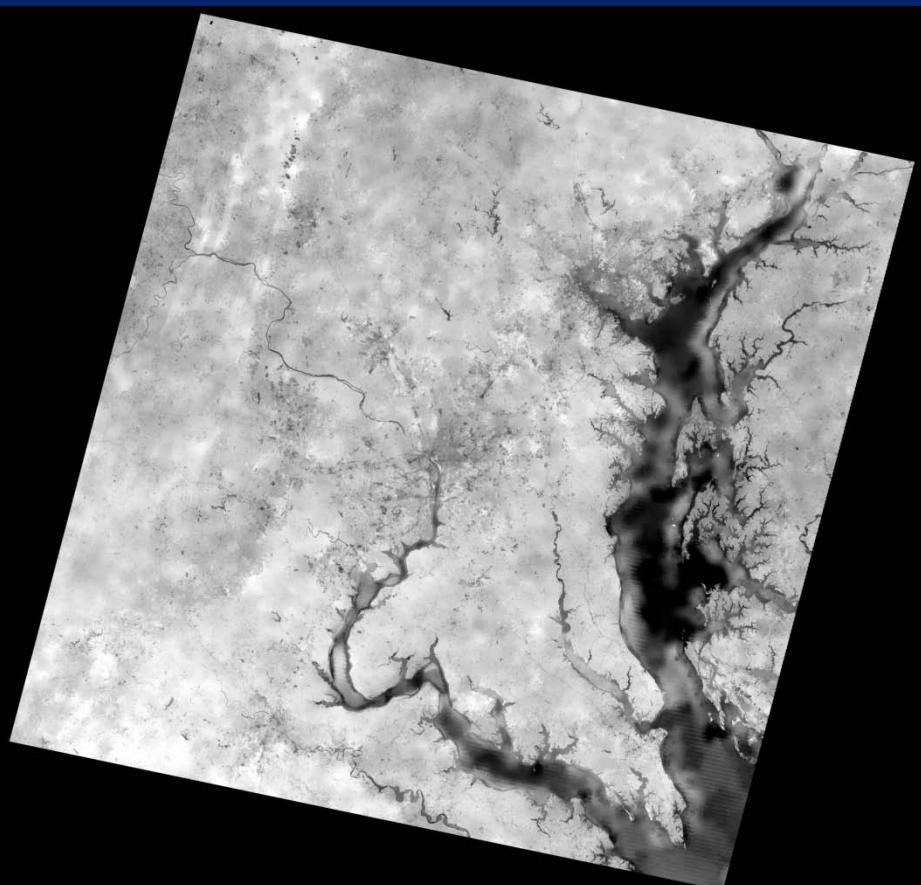


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 173-186



Original AVHRR NDVI



Predicted Landsat NDVI

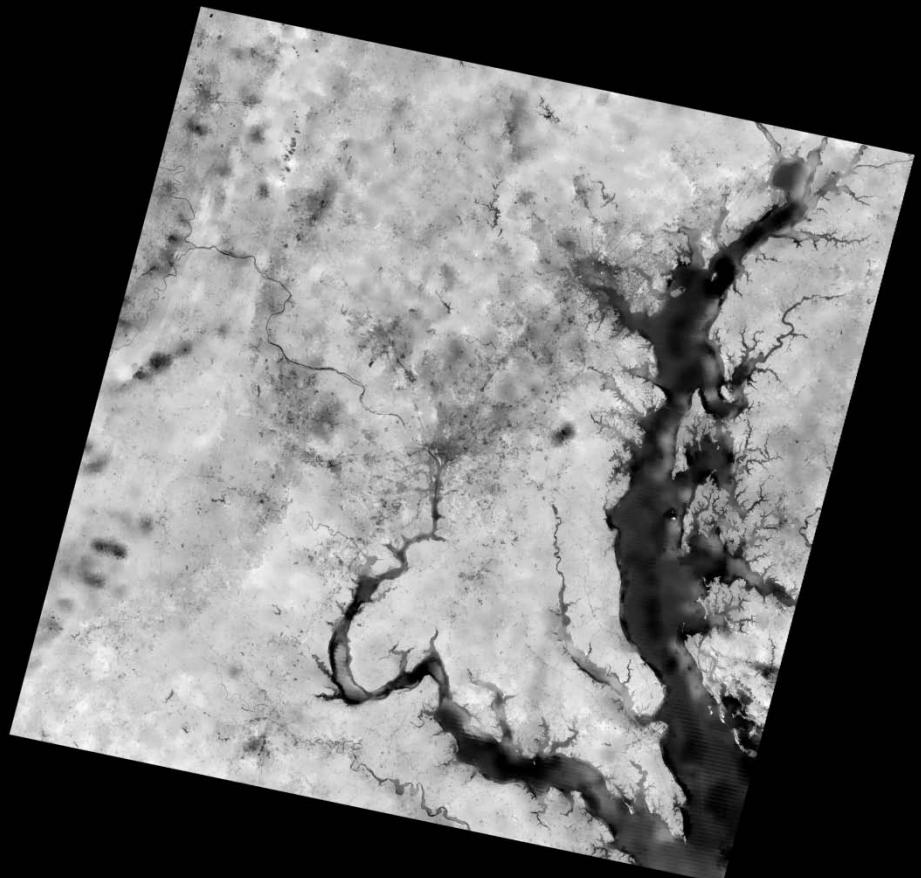


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 187-200



Original AVHRR NDVI

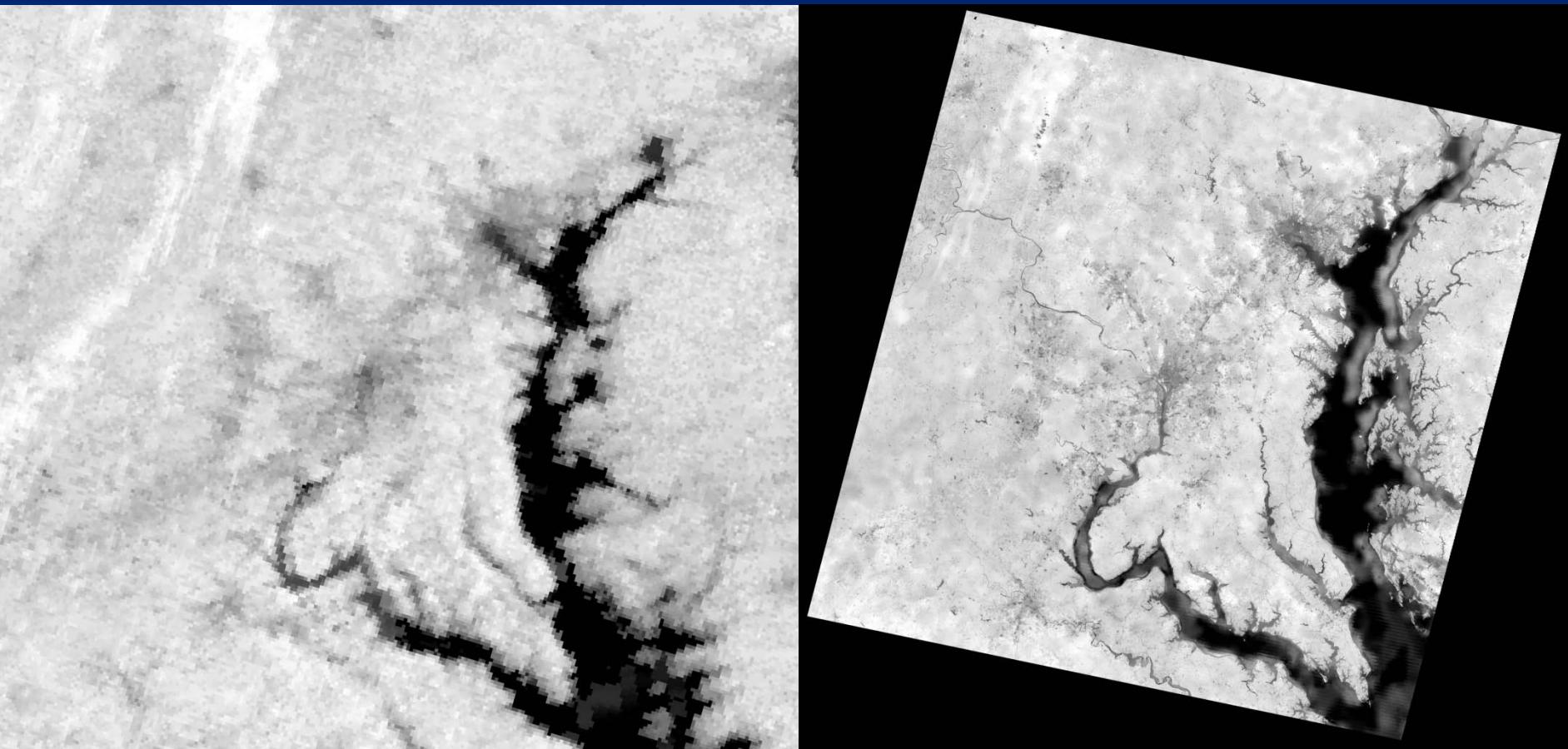


Predicted Landsat NDVI



0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 201-214



Original AVHRR NDVI

Predicted Landsat NDVI



0.0

0.1

0.2

0.3

0.4

0.5

0.6

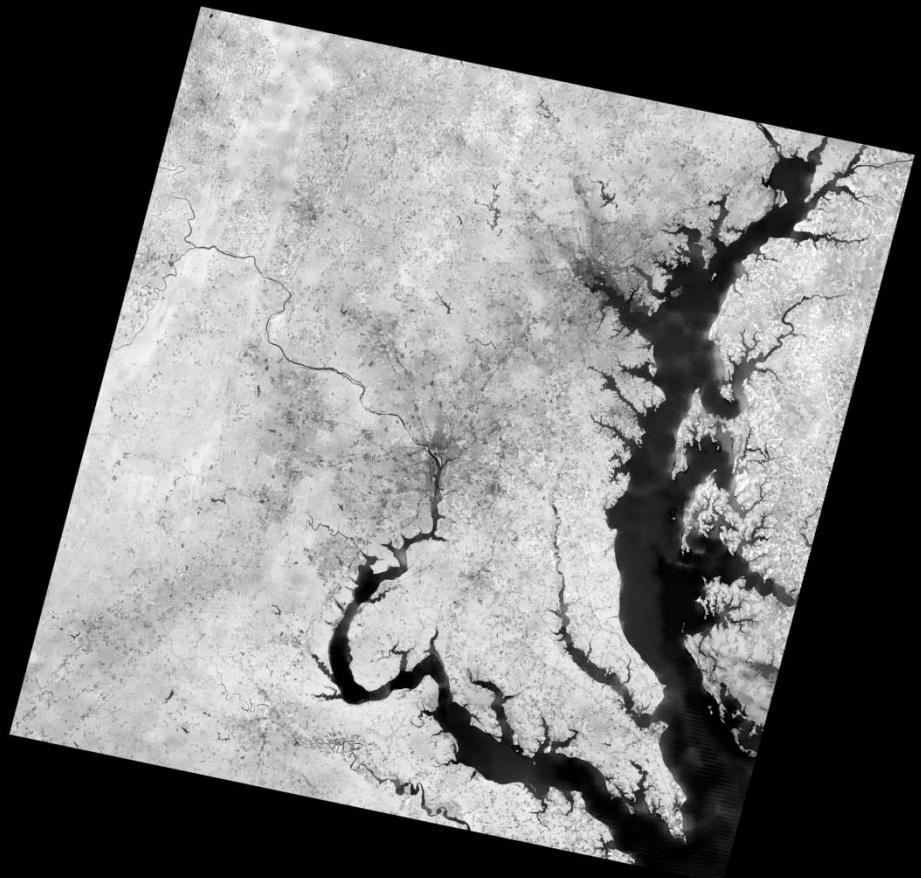
0.7

0.8

# Fused NDVI for 1990 215-228



Original AVHRR NDVI

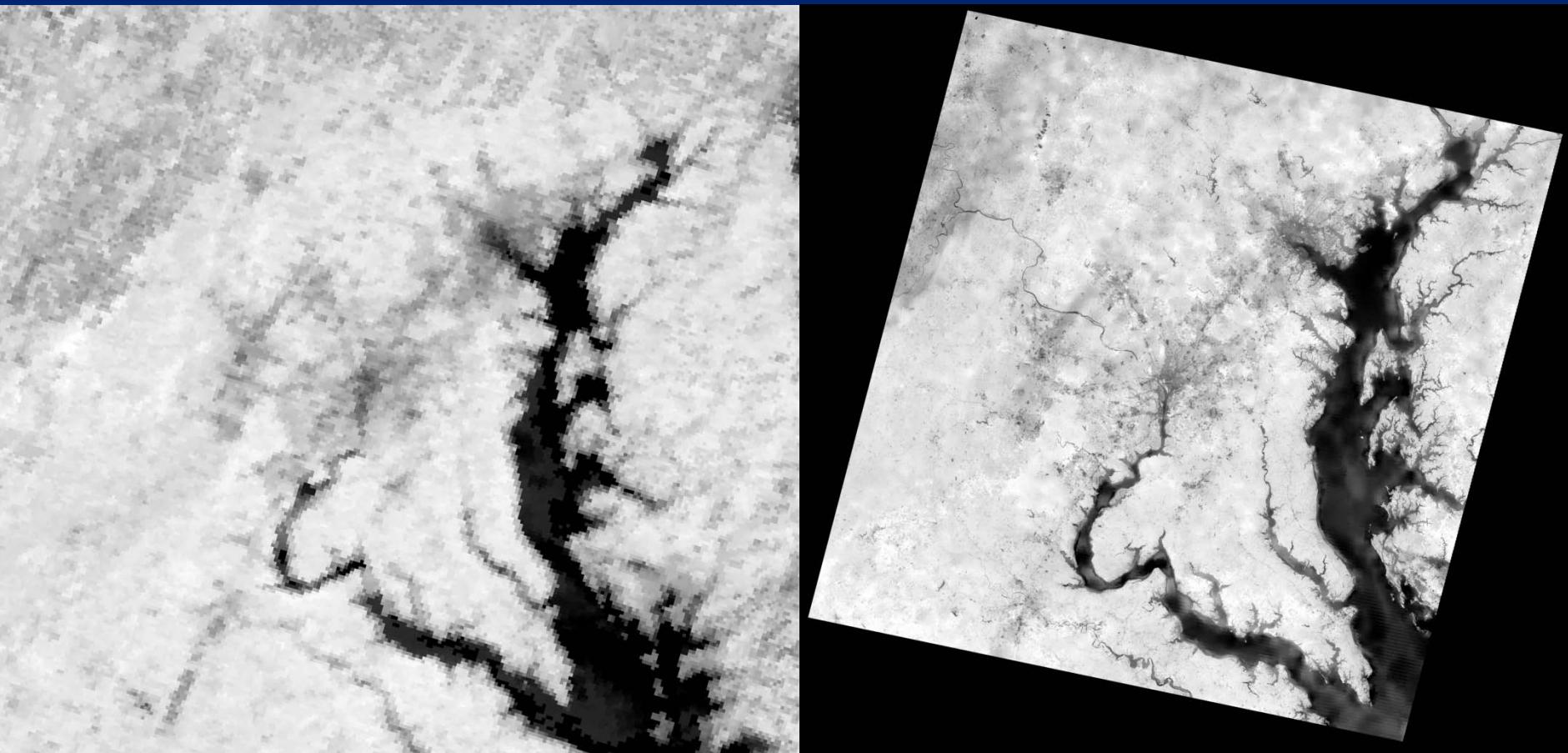


Predicted Landsat NDVI



0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

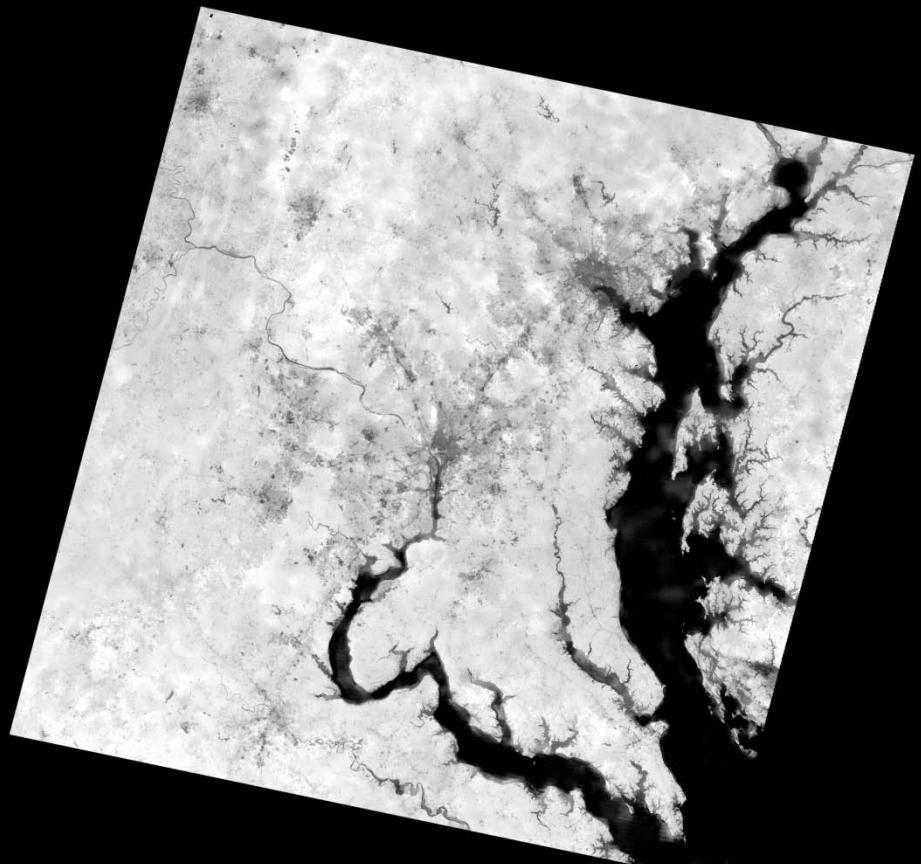
# Fused NDVI for 1990 229-242



# Fused NDVI for 1990 243-256



Original AVHRR NDVI

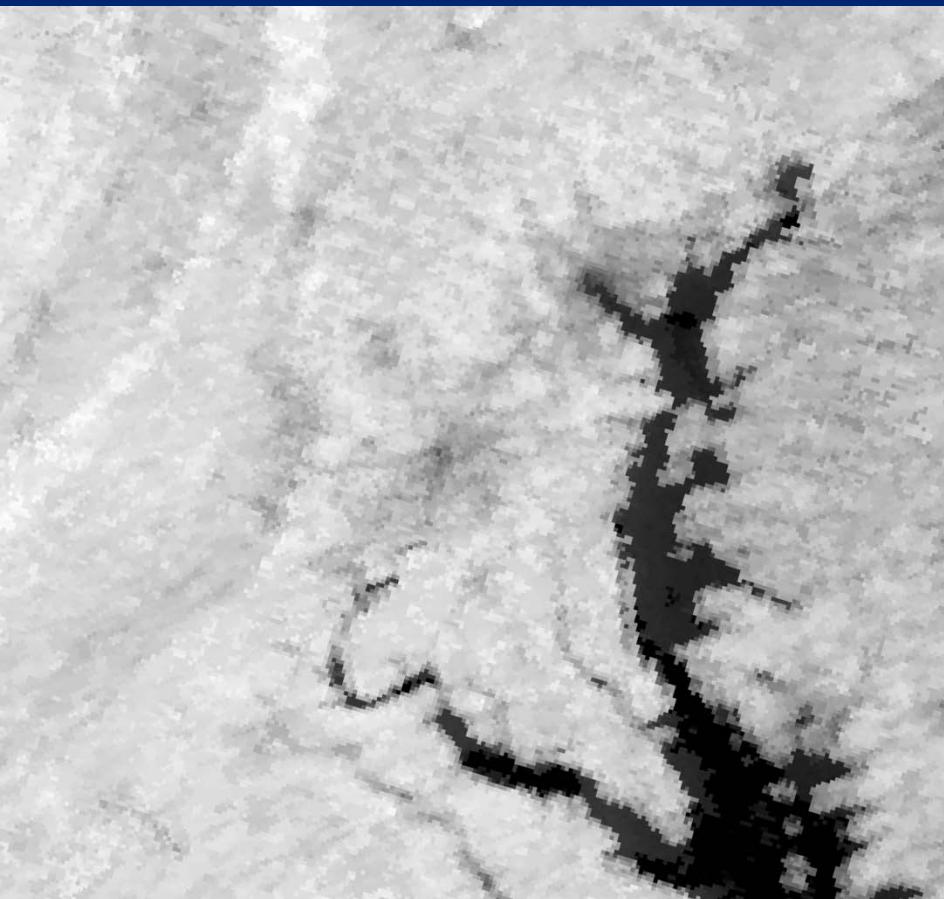


Predicted Landsat NDVI

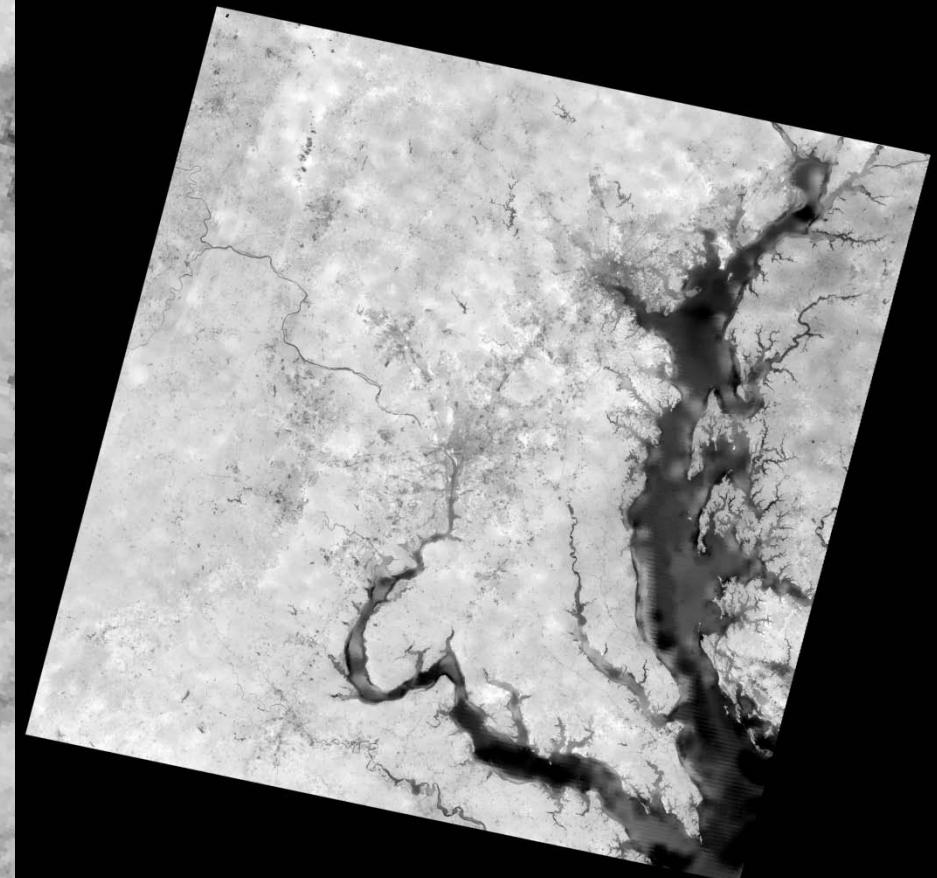


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 257-270



Original AVHRR NDVI

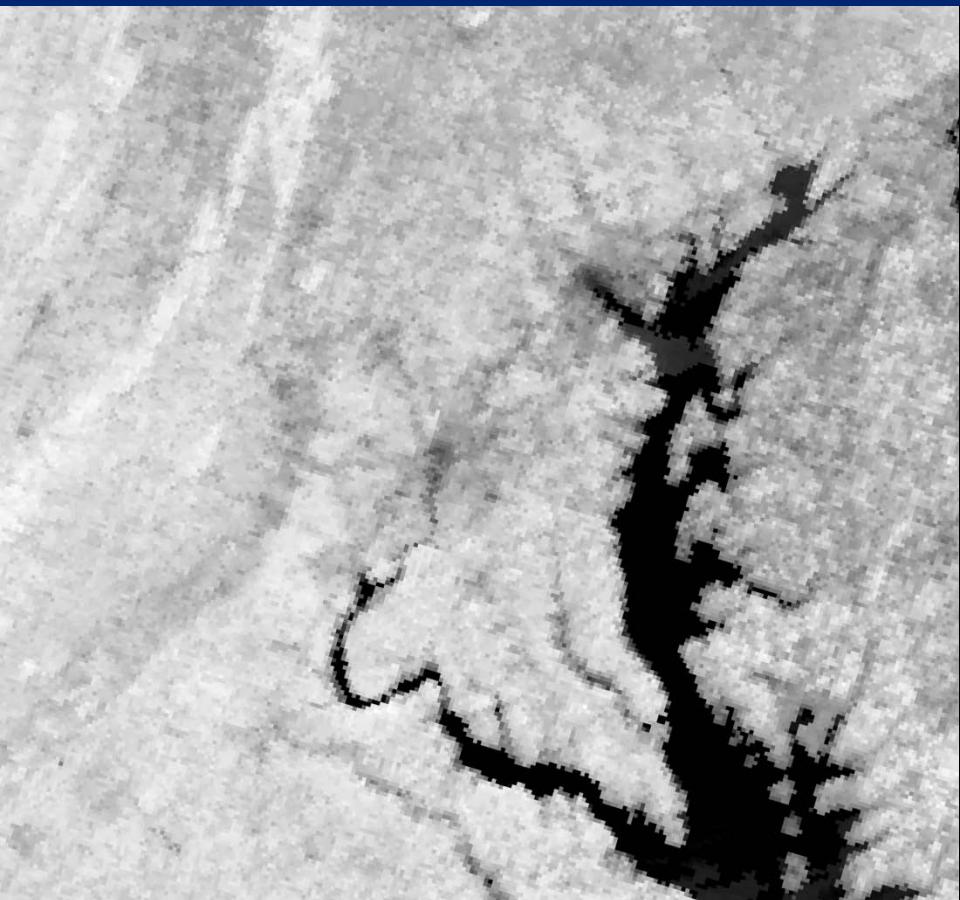


Predicted Landsat NDVI

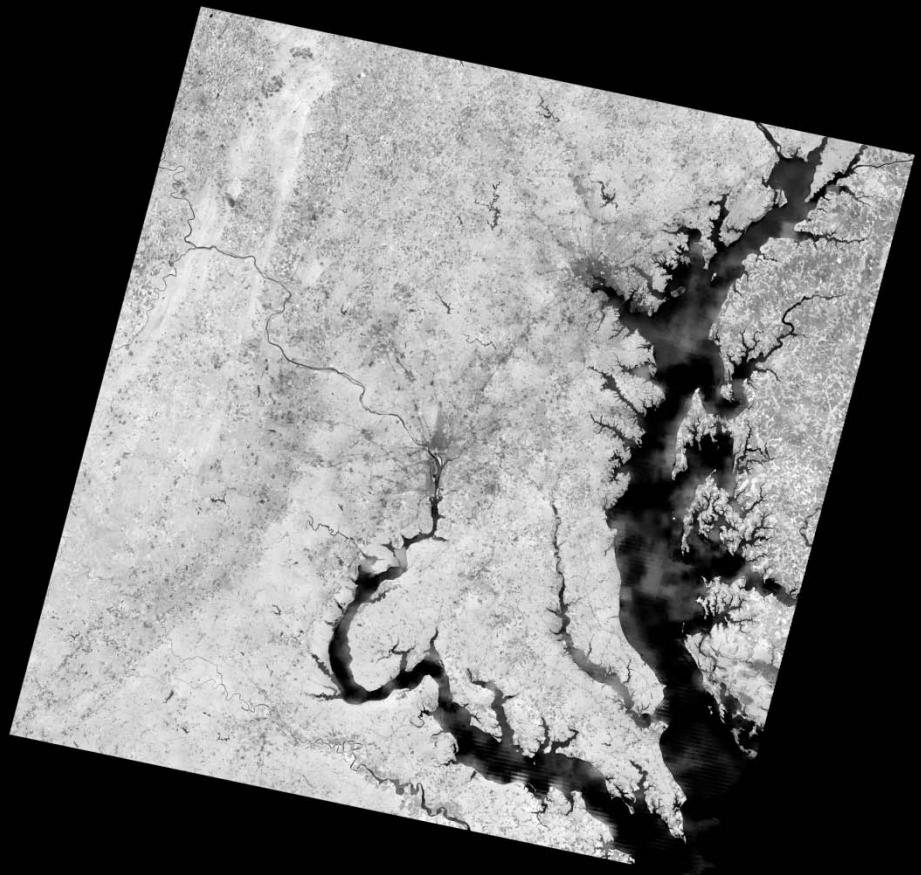


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 271-284



Original AVHRR NDVI



Predicted Landsat NDVI

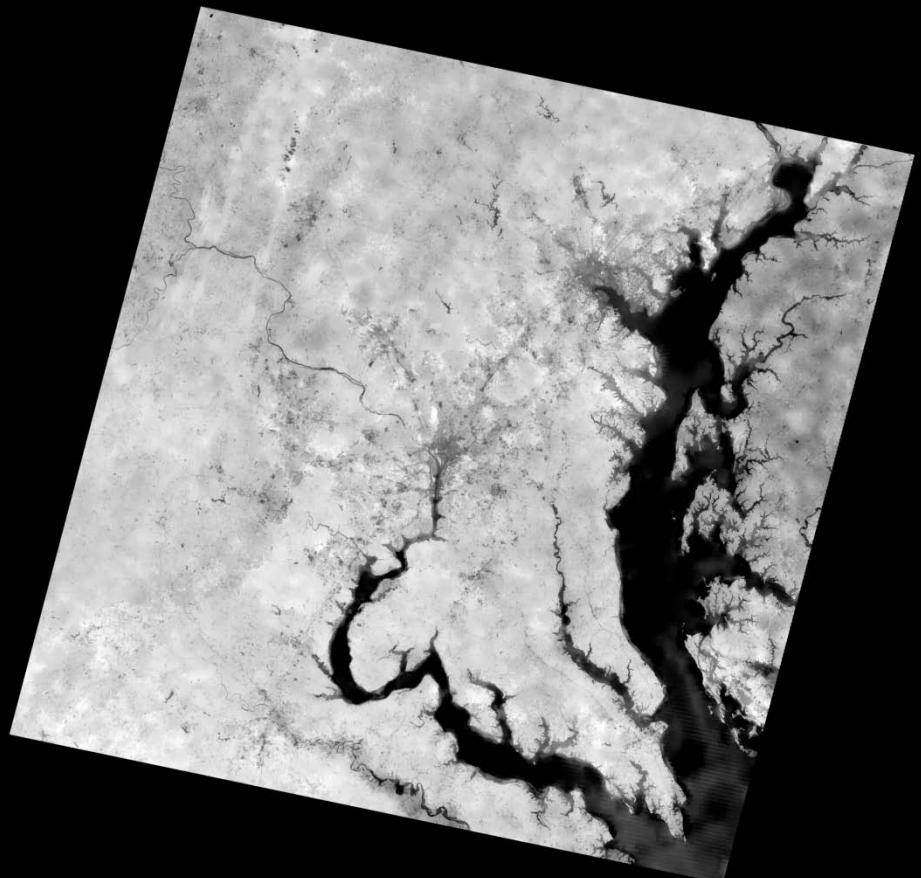


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 285-298



Original AVHRR NDVI



Predicted Landsat NDVI

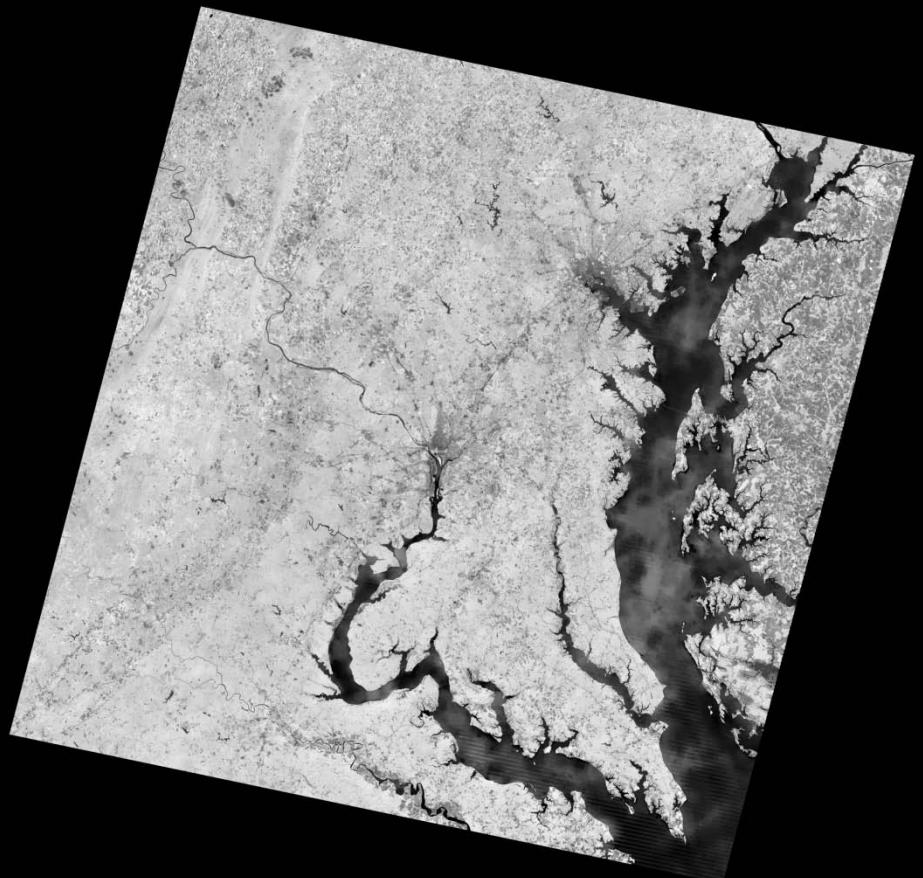


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 299-312



Original AVHRR NDVI



Predicted Landsat NDVI

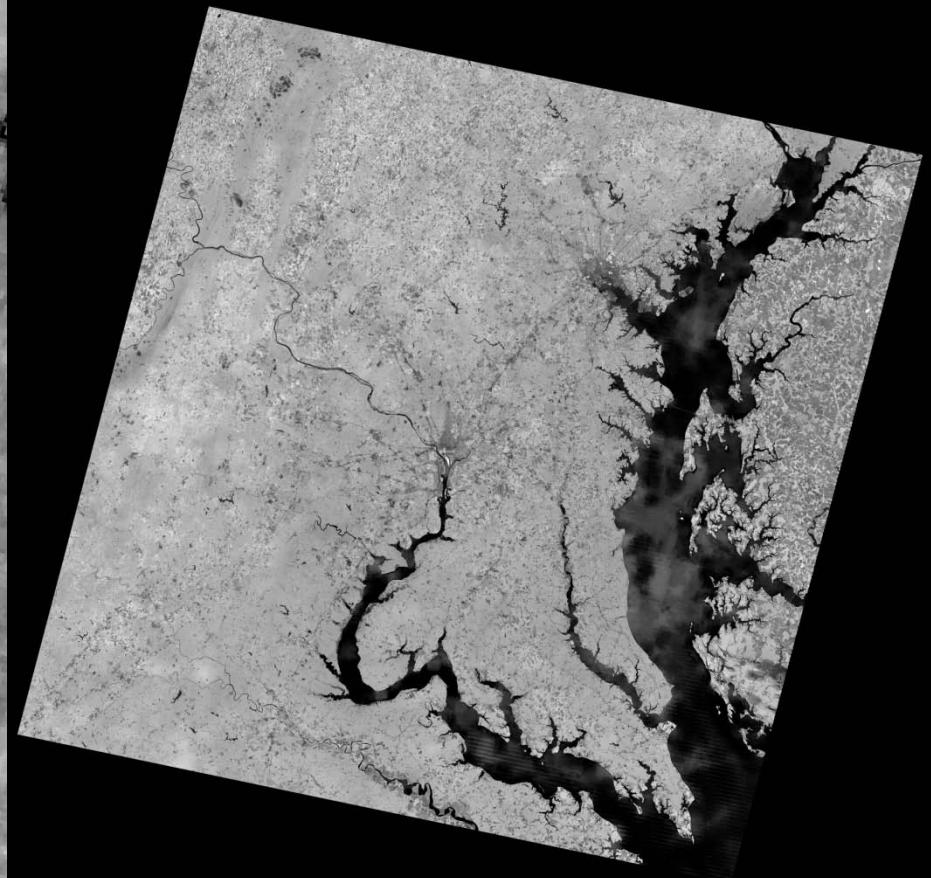


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 313-326



Original AVHRR NDVI



Predicted Landsat NDVI

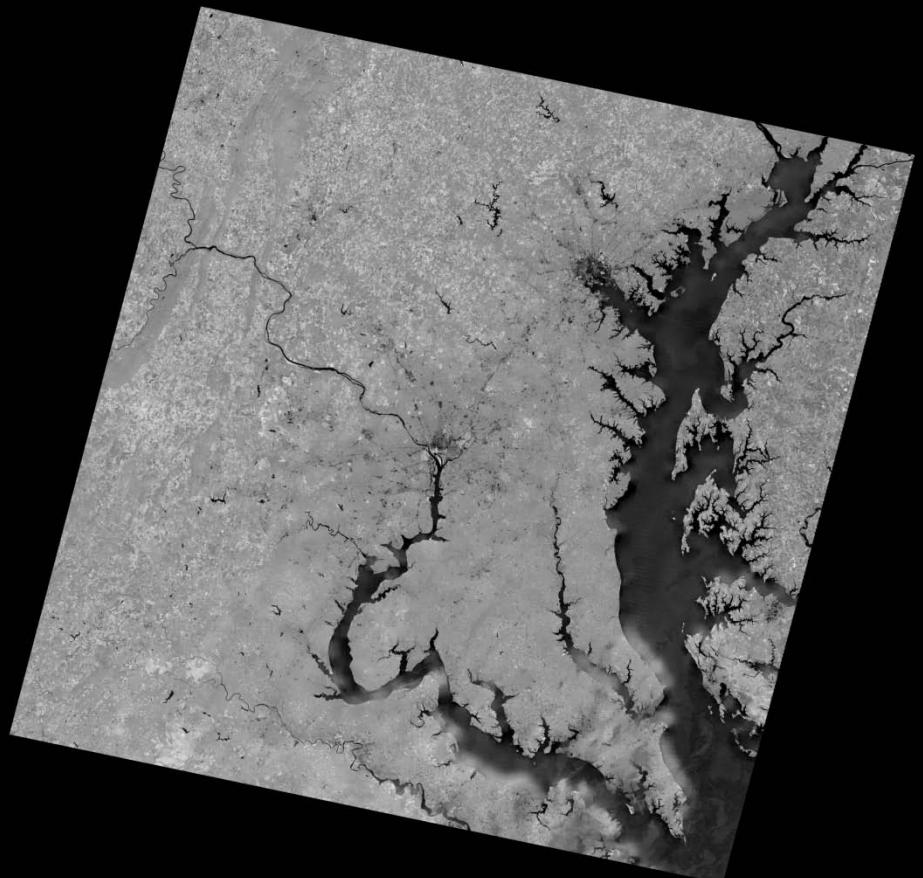


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 327-340



Original AVHRR NDVI



Predicted Landsat NDVI



0.0

0.1

0.2

0.3

0.4

0.5

0.6

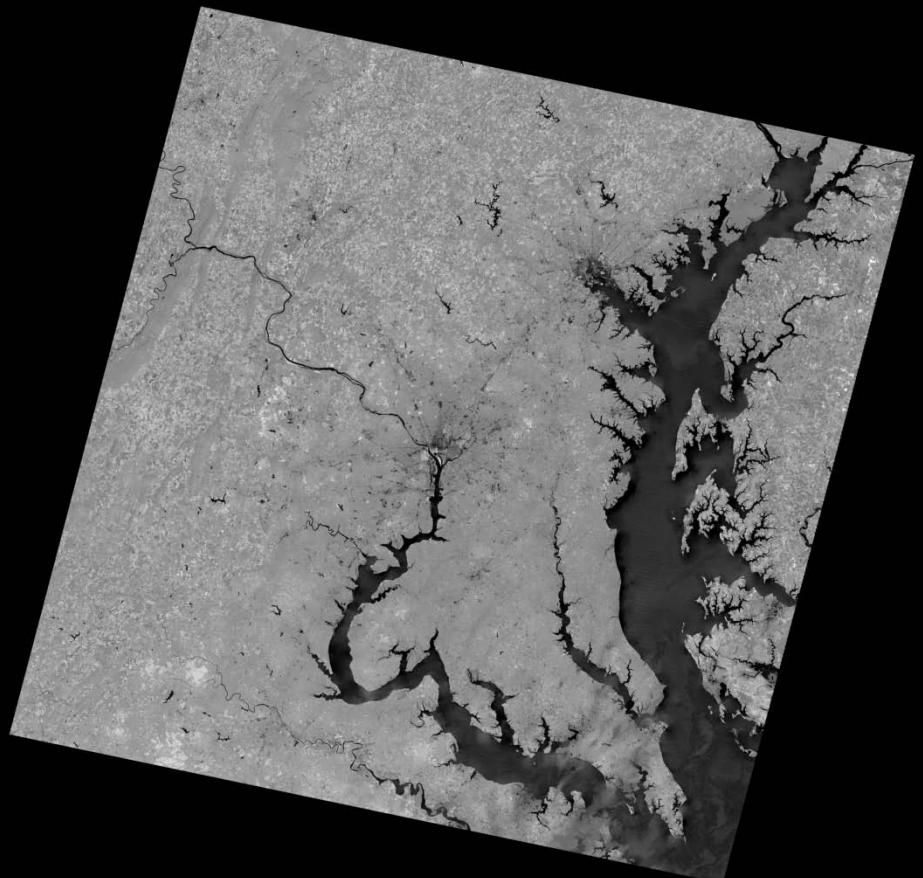
0.7

0.8

# Fused NDVI for 1990 341-354



Original AVHRR NDVI



Predicted Landsat NDVI

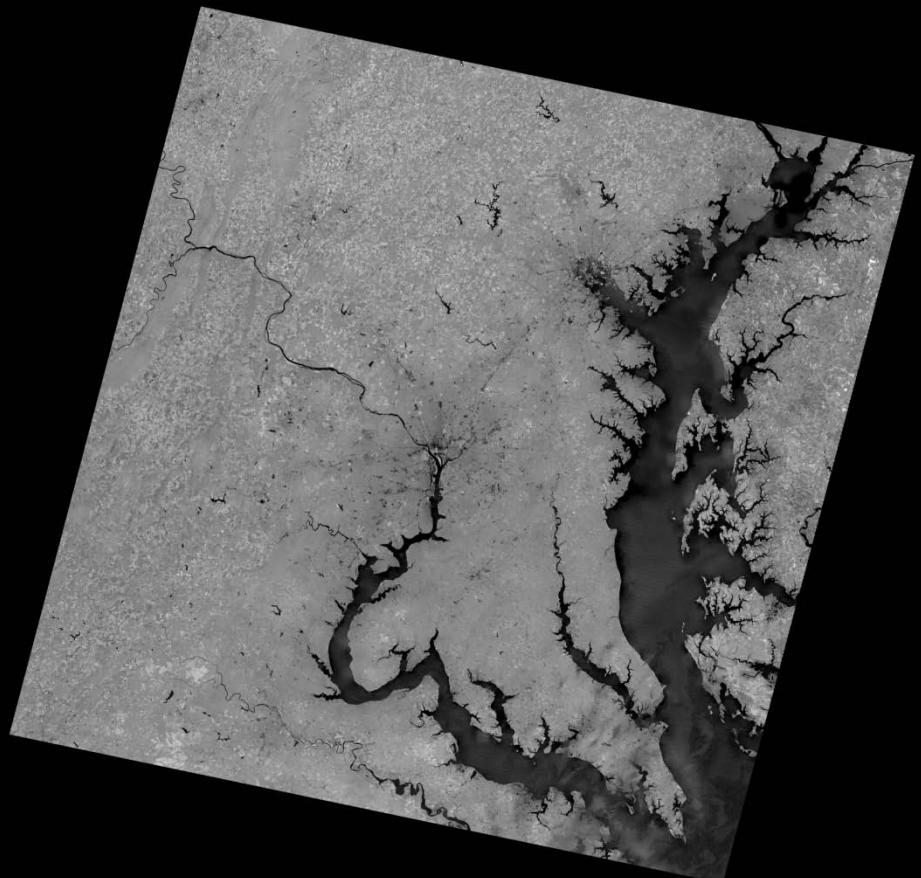


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Fused NDVI for 1990 355-1991 003



Original AVHRR NDVI

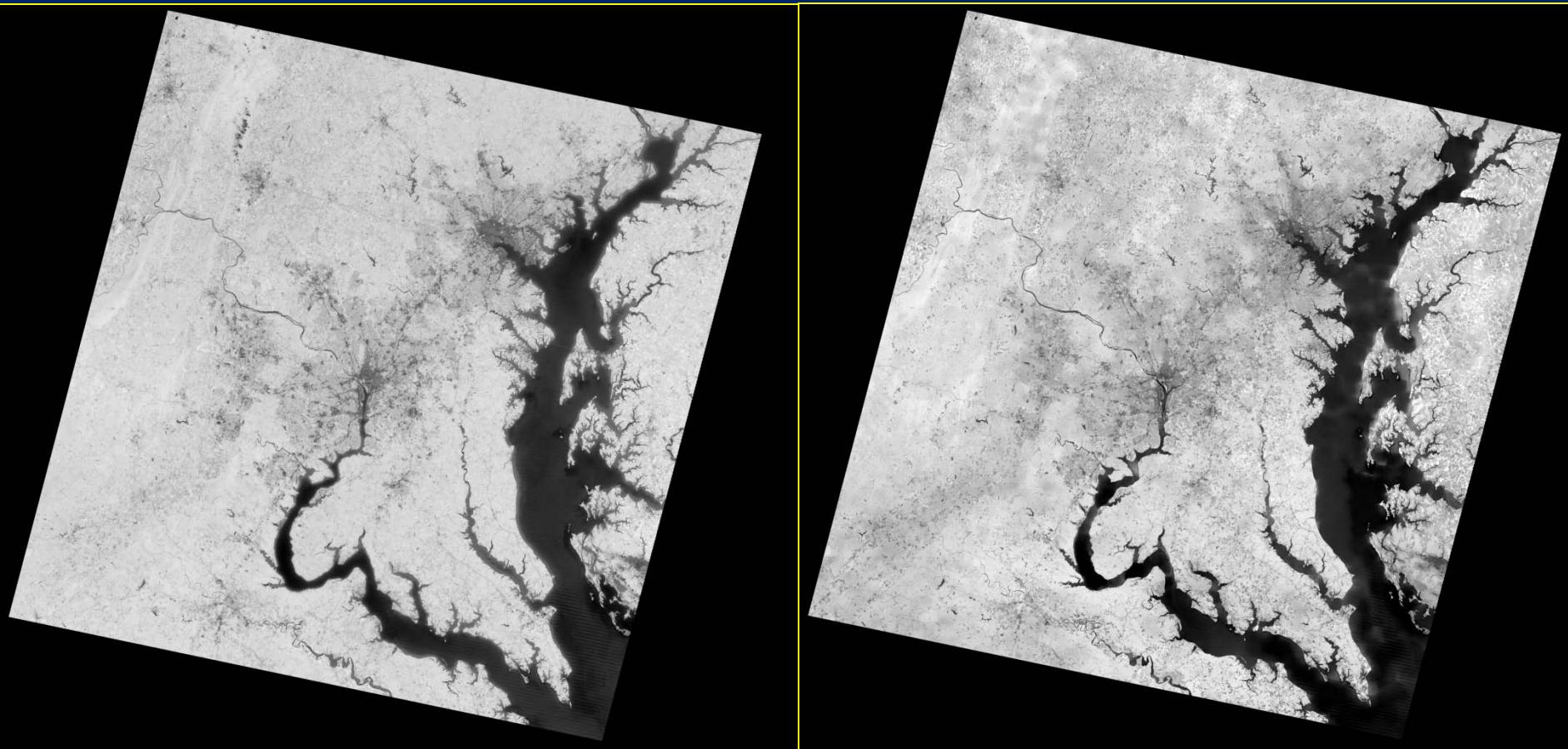


Predicted Landsat NDVI



0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

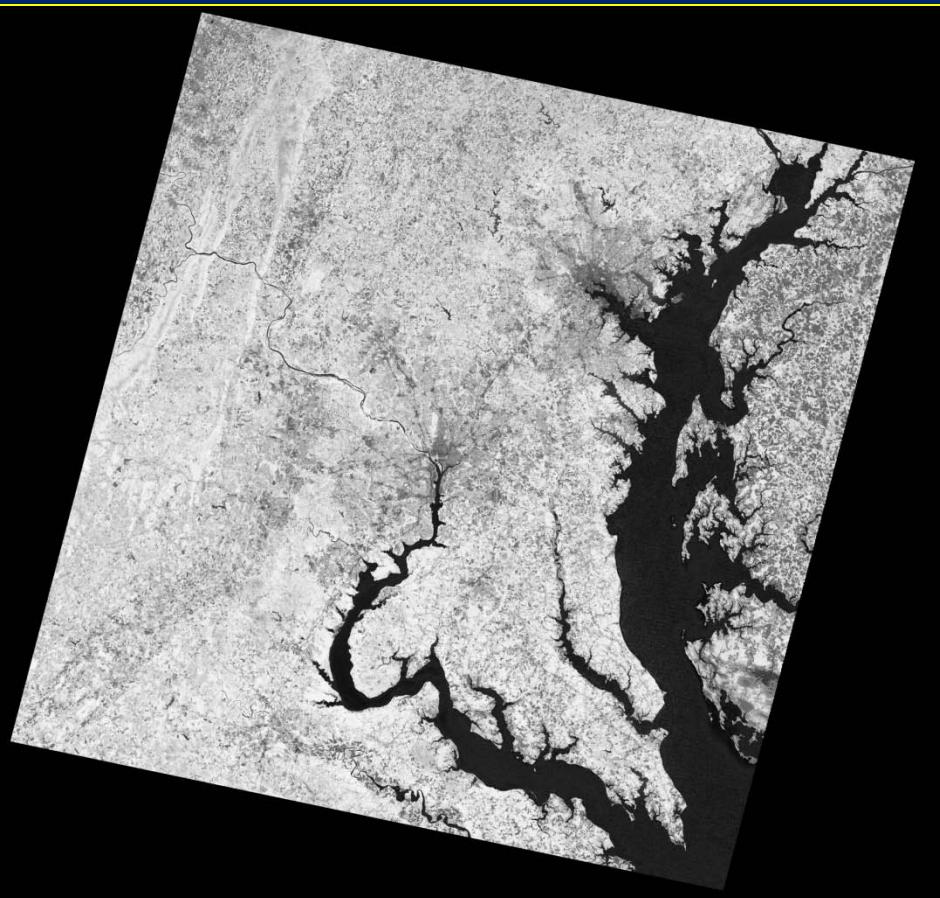
# Result for 1990-224



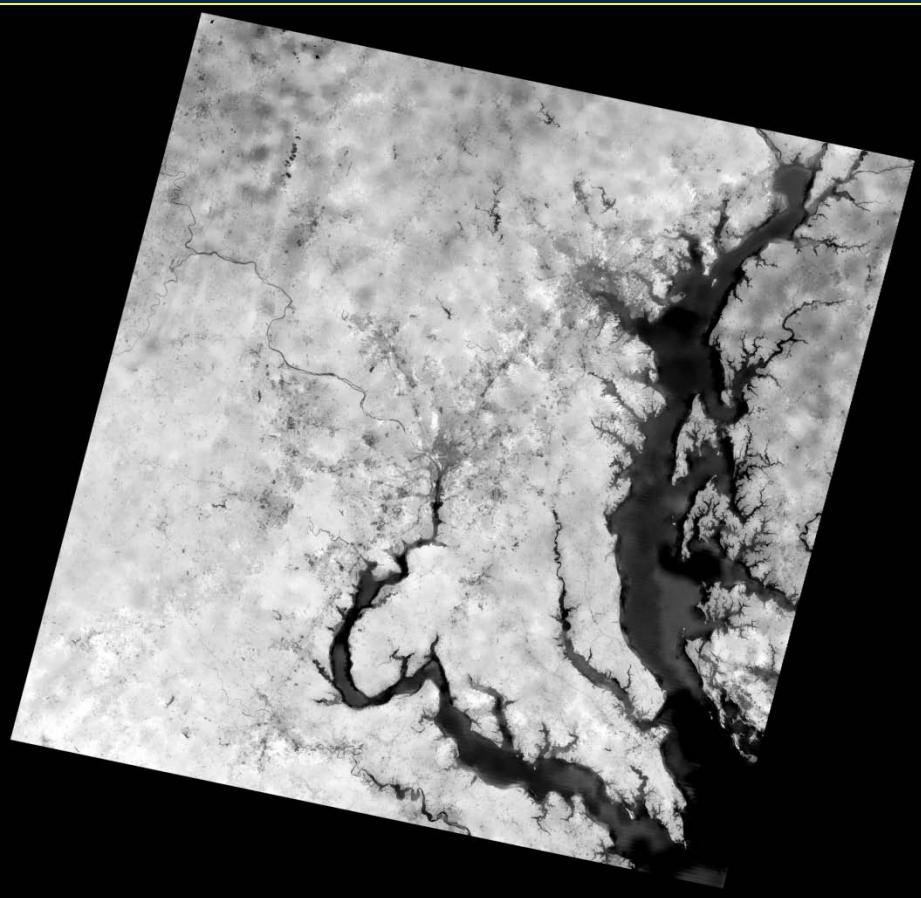
Landsat adjusted NDVI for 224 (TM)

Predicted NDVI used 128 (MSS) and 288 (TM)

# Result for 1990-128



Landsat adjusted NDVI for 128 (MSS)

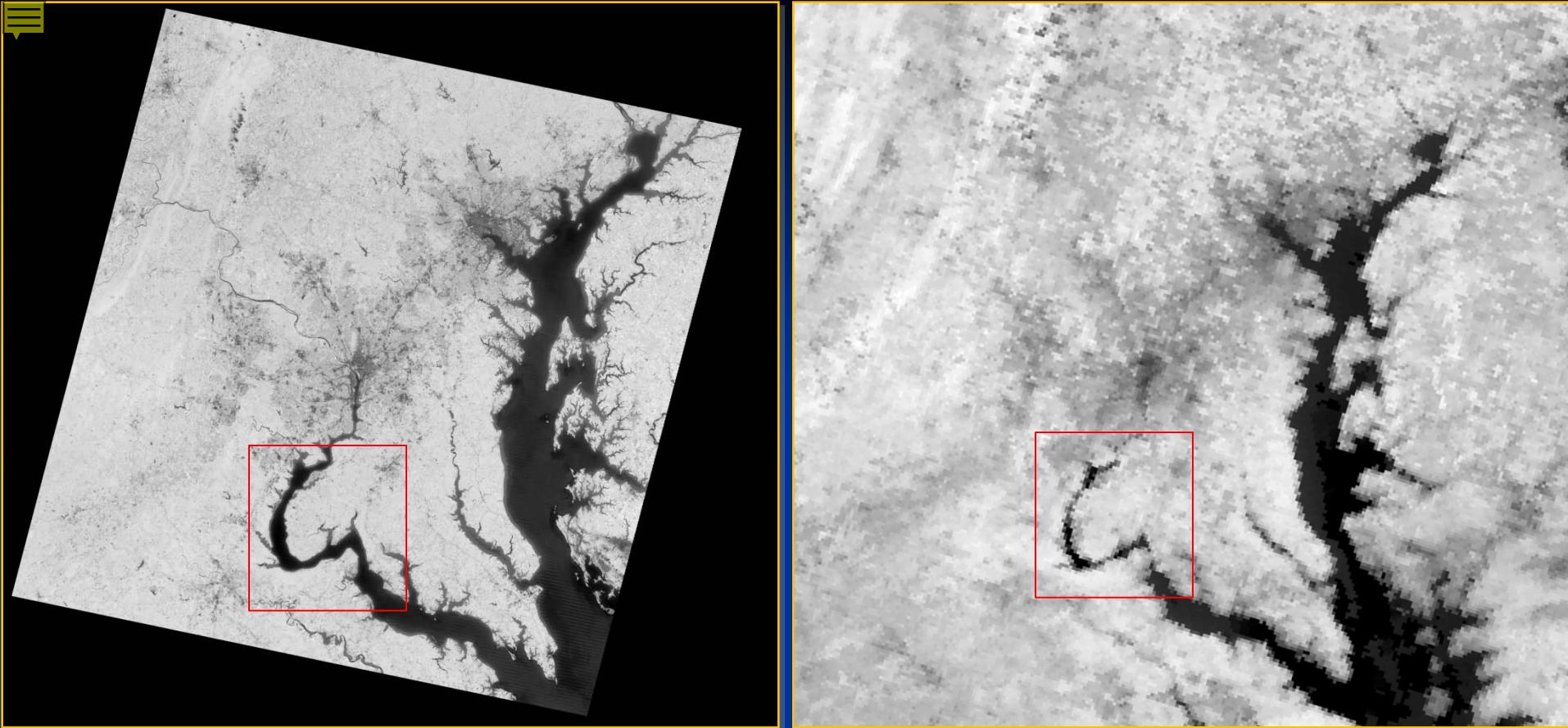


Predicted NDVI used 224 (TM)

# Verification Summary

Validation Dates	Averaged Difference (60m)		Averaged Absolute Difference (60m)		Correlation (1km)	Scattering Plot (1km)	
	Input	Predict	Input	Predict	AVHRR	Input	Predict
1990-128 (use 224)	-0.033	-0.001	0.080	0.084	0.86		
1990-224 (128, 288)	-0.033 0.036	0.013	0.080 0.075	0.055	0.86 0.88	See 128-224 224-288	
1990-288 (use 224)	0.036	-0.004	0.075	0.073	0.88		
1990-320 (use 288)	0.074	0.005	0.097	0.051	0.96		

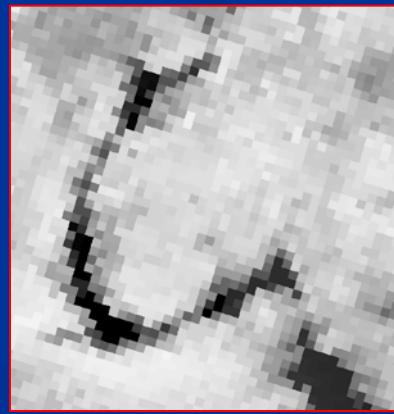
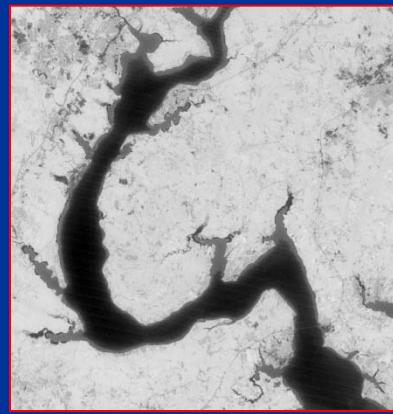
Input: observed (adjusted) NDVI on prediction day – observed (adjusted) NDVI used for prediction  
 Predict: observed (adjusted) NDVI on prediction day – predicted NDVI



## A less ideal input pair (224)

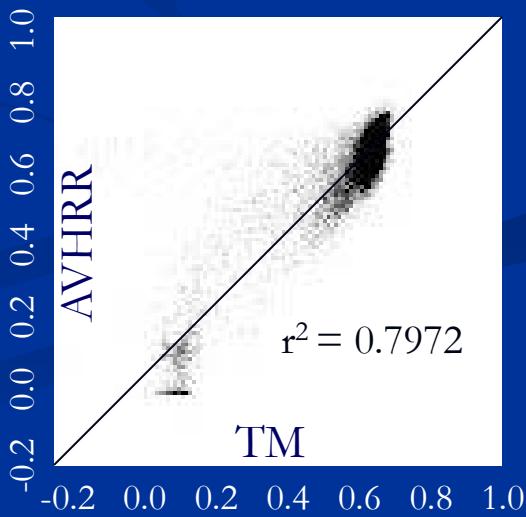
TM: 224 (8/12)

AVHRR: 215-228  
(8/3 – 8/16)

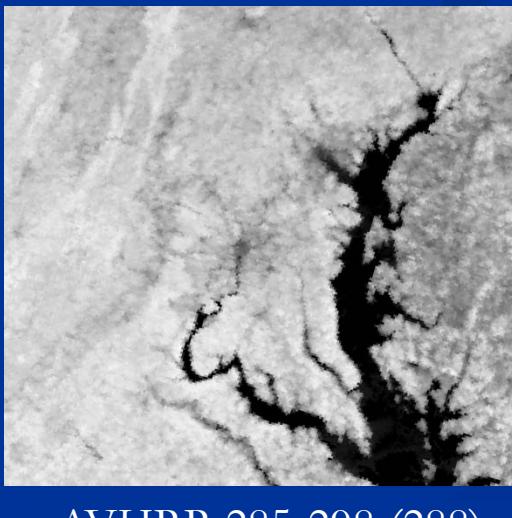
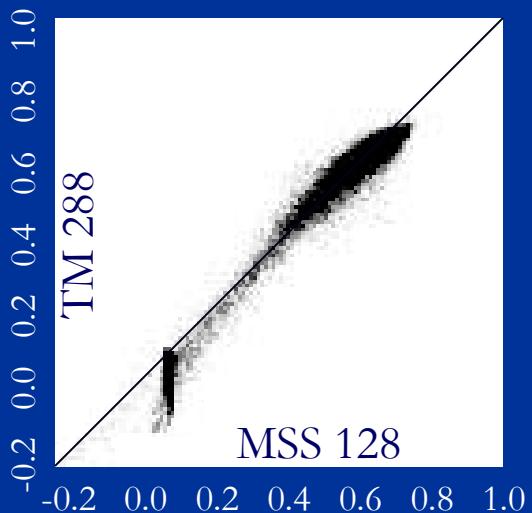
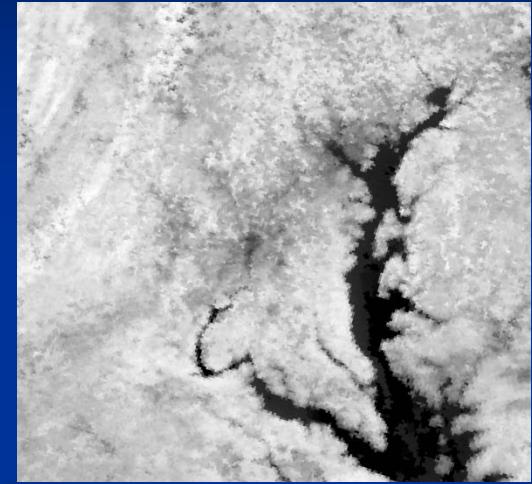
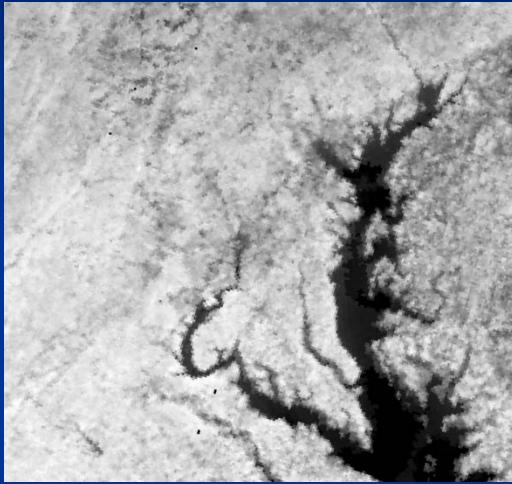
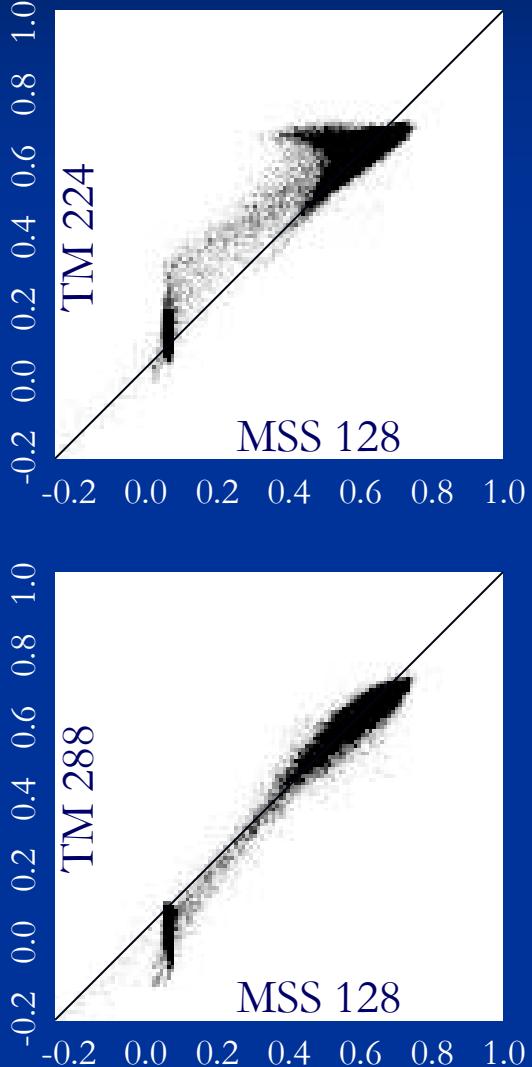


0.0 0.2 0.4 0.6 0.8

0.0 0.2 0.4 0.6 0.8

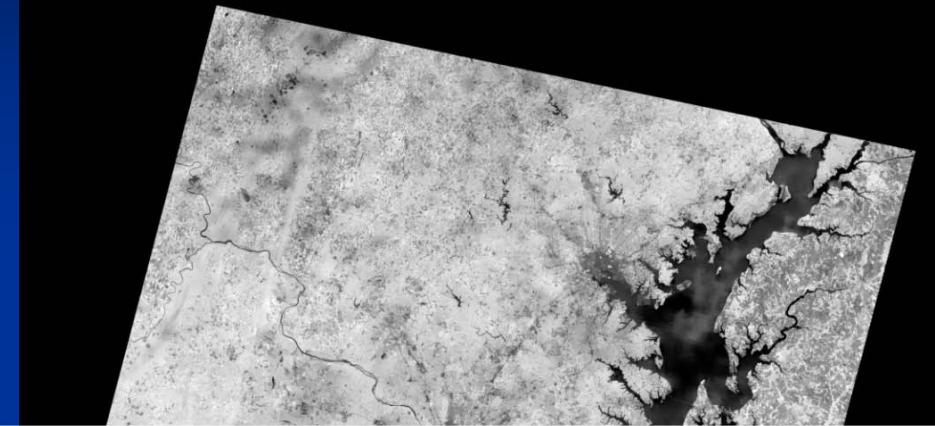
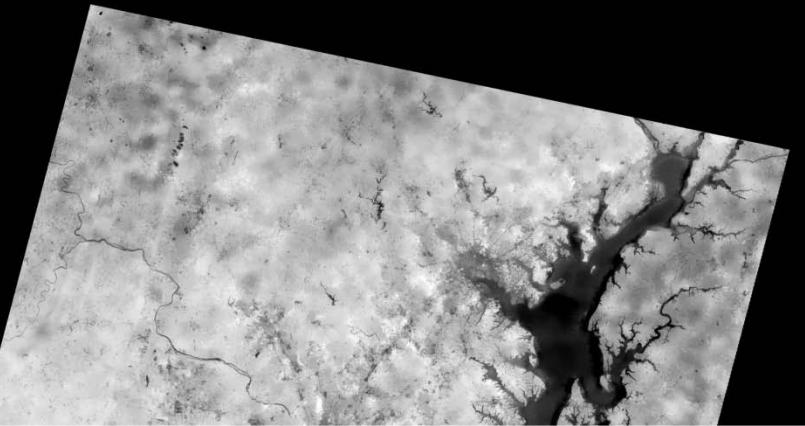


# Choose different input pairs for day 128



AVHRR	128,224	128,288
Correlation	0.860	0.917
Averaged Difference	-0.034	-0.001
Average Abs. Diff.	0.082	0.053

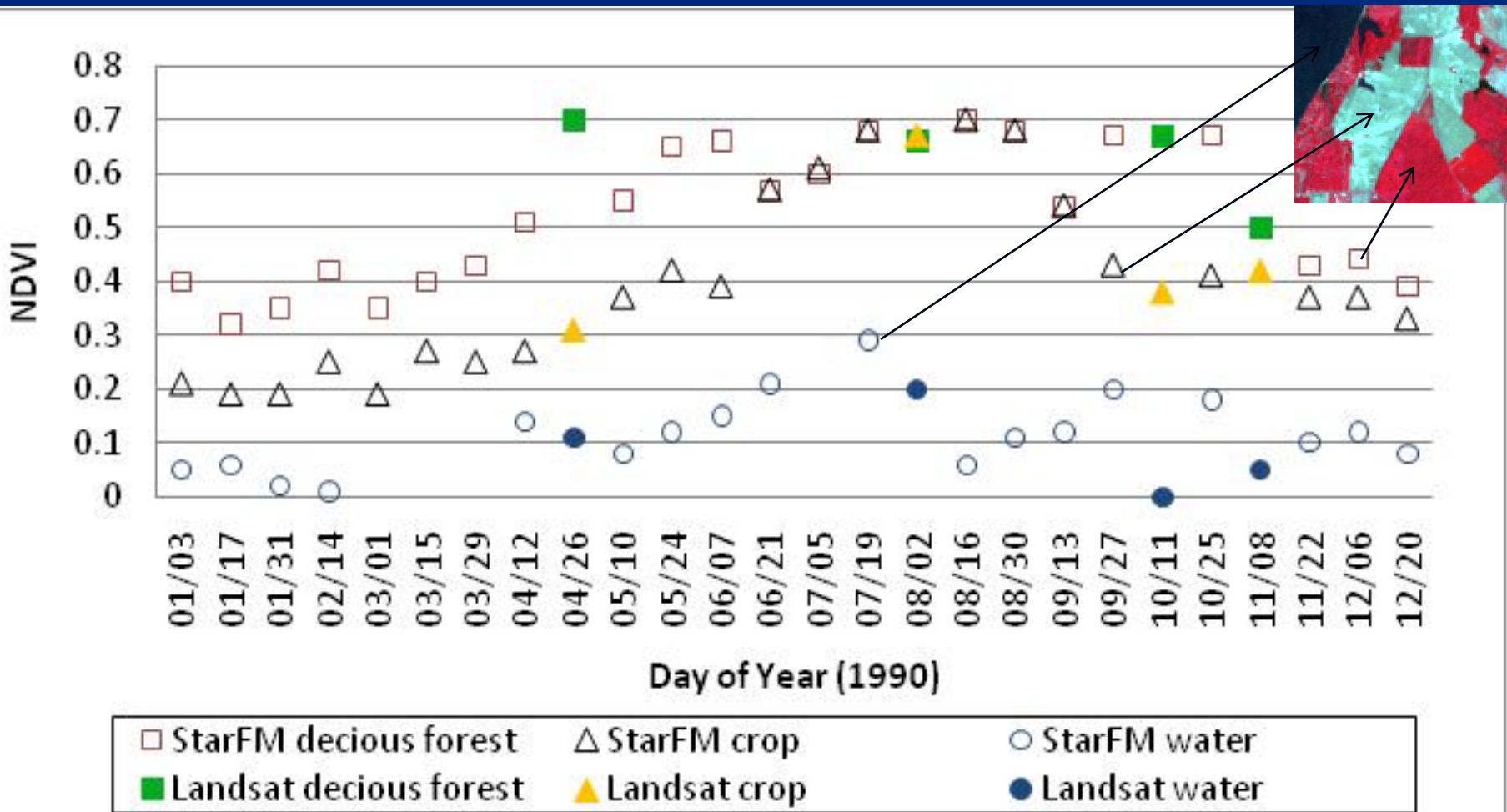
# Different Input Pairs for Day 128 Prediction



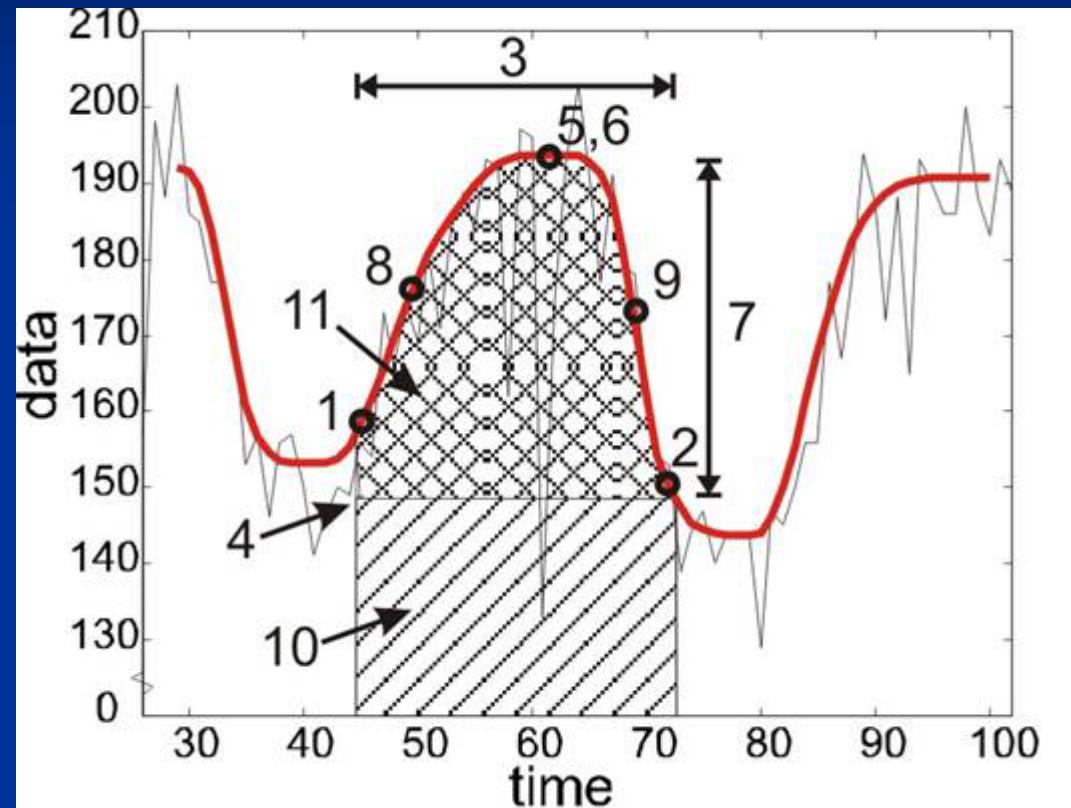
Validation Dates	Averaged Difference (60m)		Averaged Absolute Difference (60m)		Correlation (1km)	Scattering Plot (1km)	
	Input	Predict	Input	Predict	AVHRR	Input	Predict
1990-128 (use 224)	-0.033 (-0.028*)	-0.001 (-0.003*)	0.080 (0.079*)	0.084 (0.080*)	0.860		
1990-128 (use 288)	0.003 (-0.007*)	0.001 (0.001*)	0.064 (0.061*)	0.072 (0.064*)	0.917		

(\* land pixels only)

# Landsat NDVI Time Series (prediction + observation)



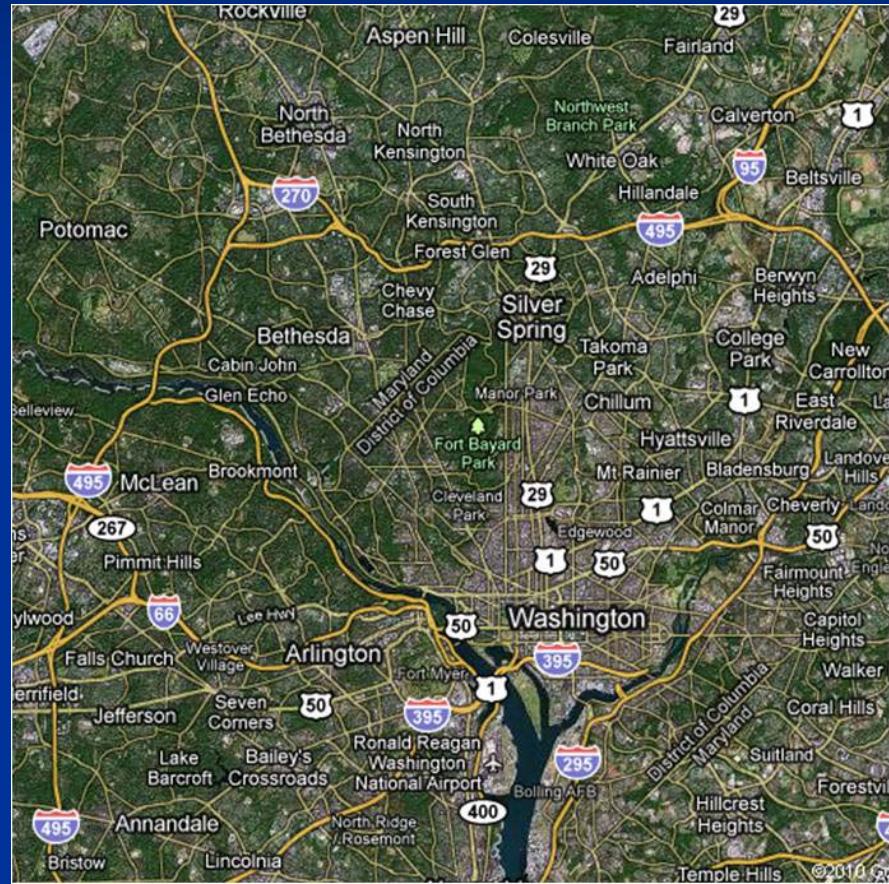
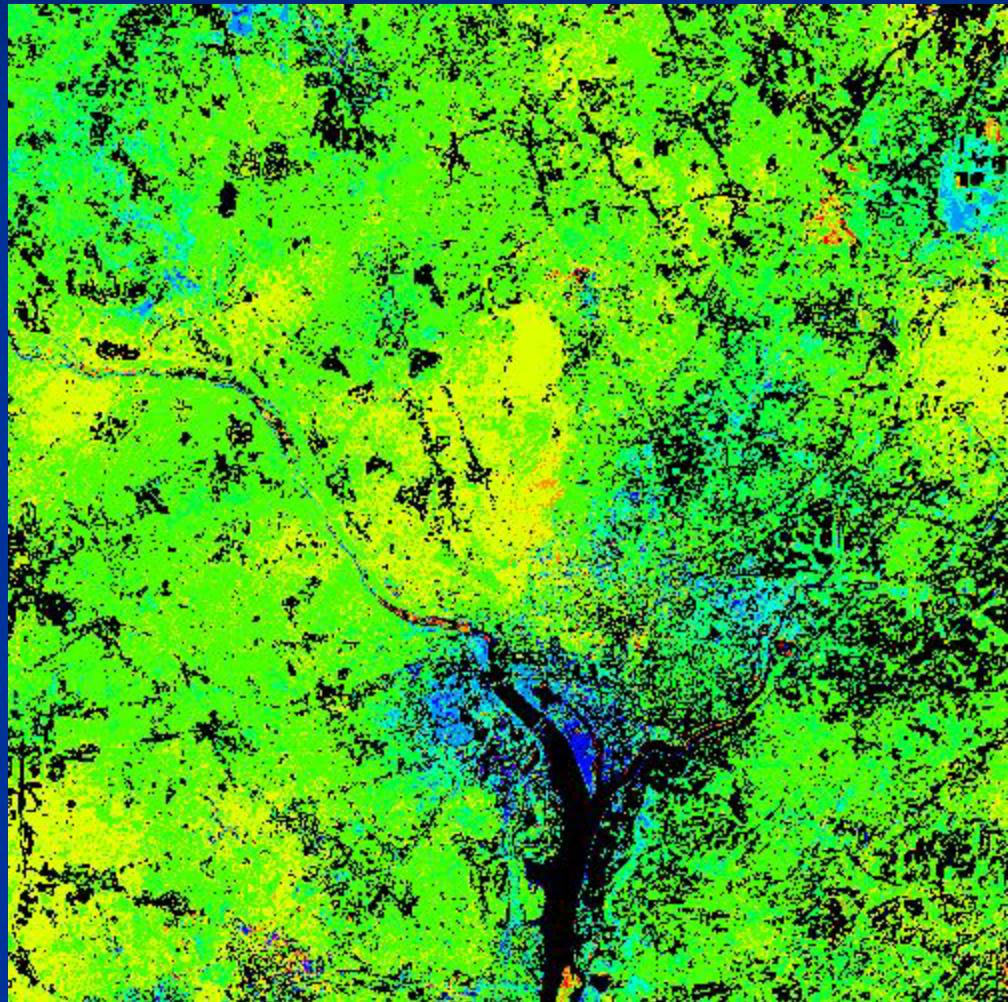
# Phenology Metrics from Timesat



- 1) time for the start of the season
- 2) time for the end of the season
- 3) length of the season
- 4) base level
- 5) time for the middle of the season
- 6) peak value of the fitted function
- 7) seasonal amplitude
- 8) left slope
- 9) right slope
- 10) large seasonal integral
- 11) small seasonal integral

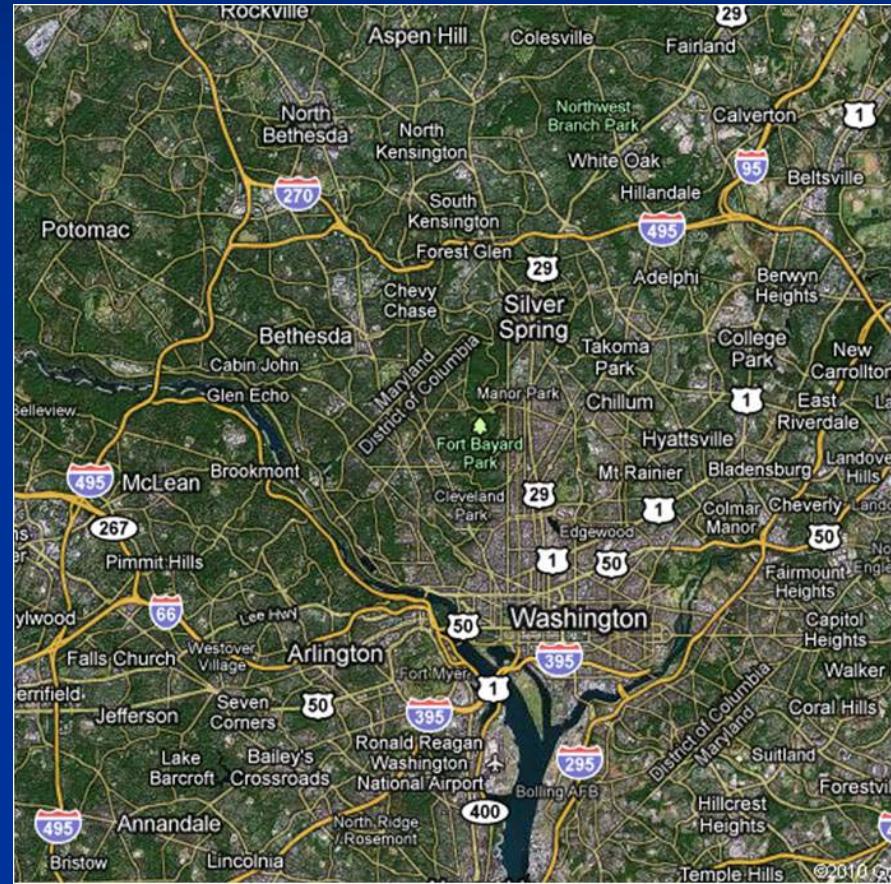
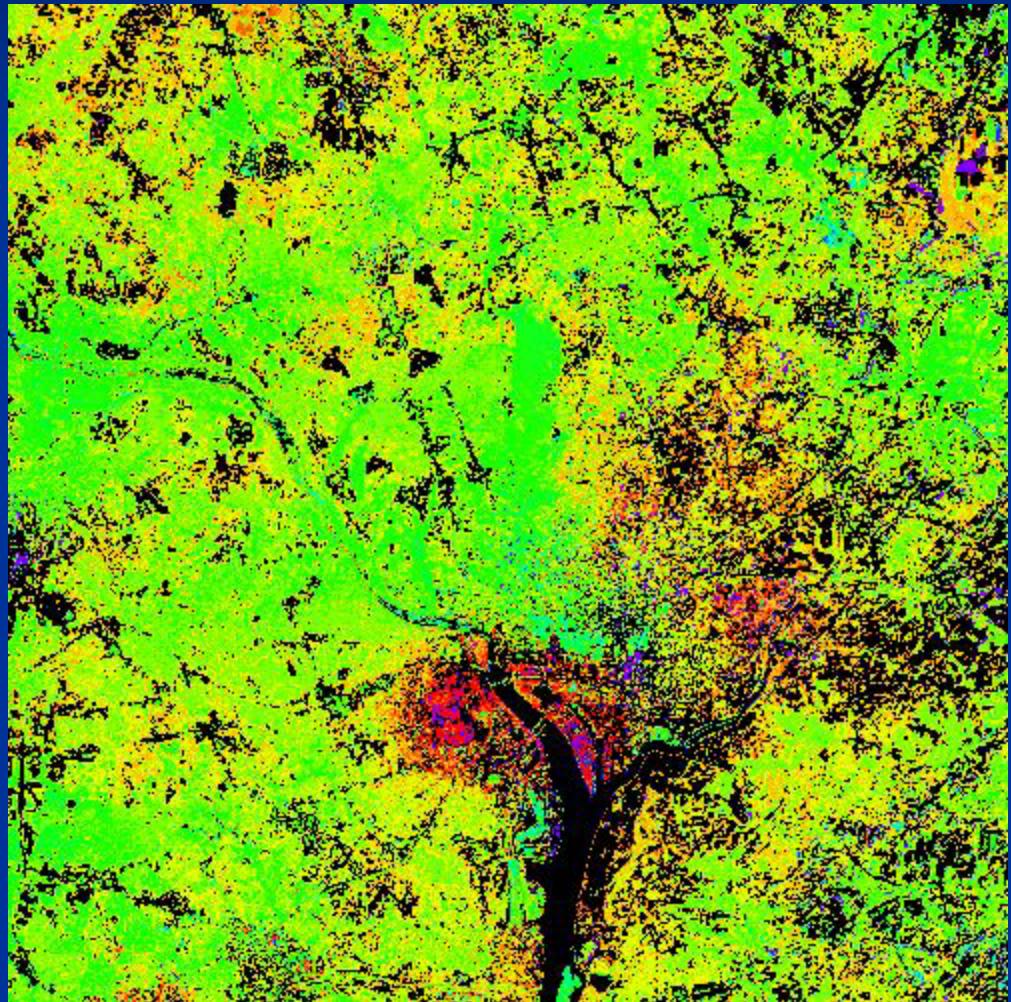
Per Jonsson & Lars Eklund, TIMESAT - a program for analyzing time-series of satellite sensor data, Computers & Geosciences, 30:833-845, 2004.  
Gao etc., An algorithm to produce temporally and spatially continuous MODIS LAI time series, IEEE Geoscience and Remote Sensing Letters, 5(1):60-64, 2008.

# Relative Greenup Date (1990) from Landsat NDVI Time-series



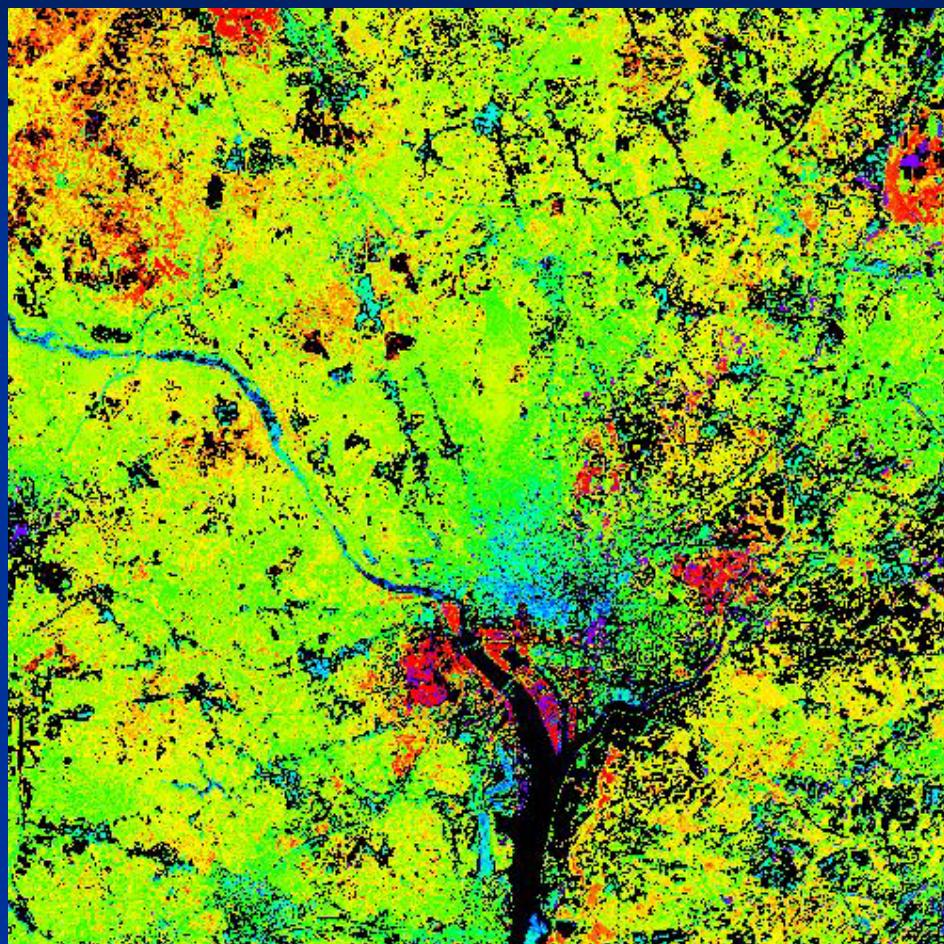
Jan 1      Feb 1      Mar 1      Apr 1      May 1

# Length of Green Season from Landsat NDVI Time-series

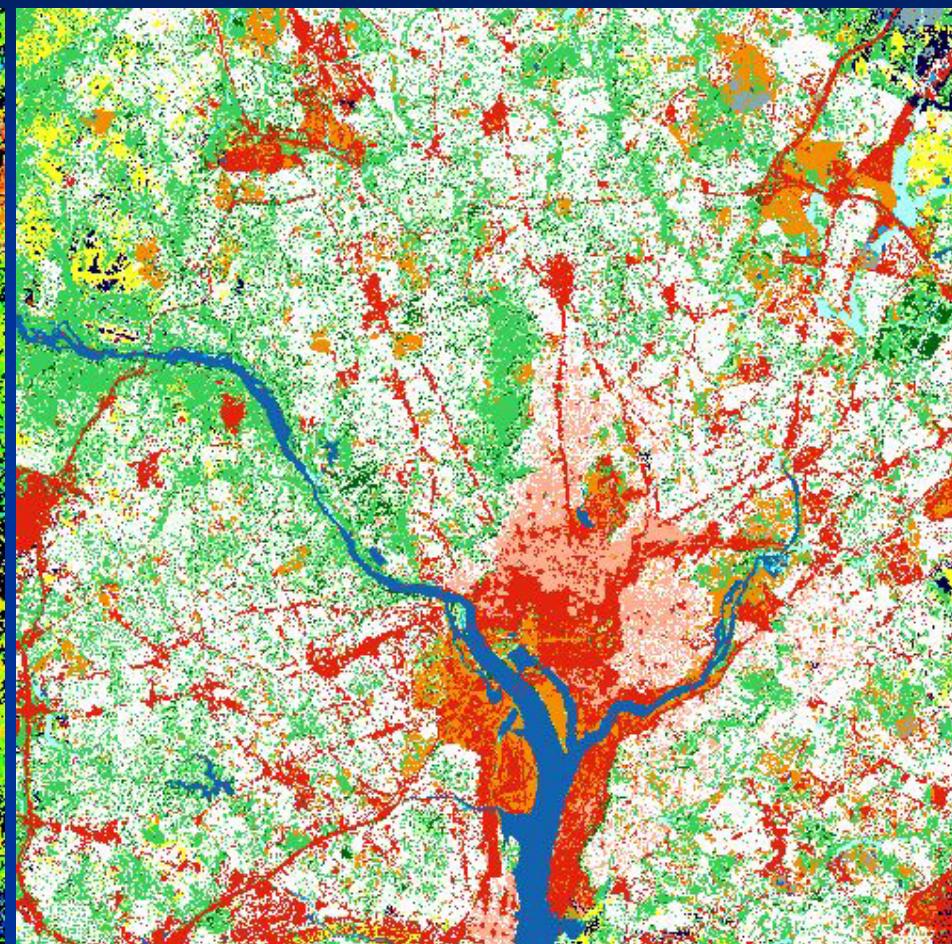


140 170 200 230 260 290

# Annual Integral of NDVI (1990)



NDVI Integral of 1990



NLCD 1992



# Conclusion

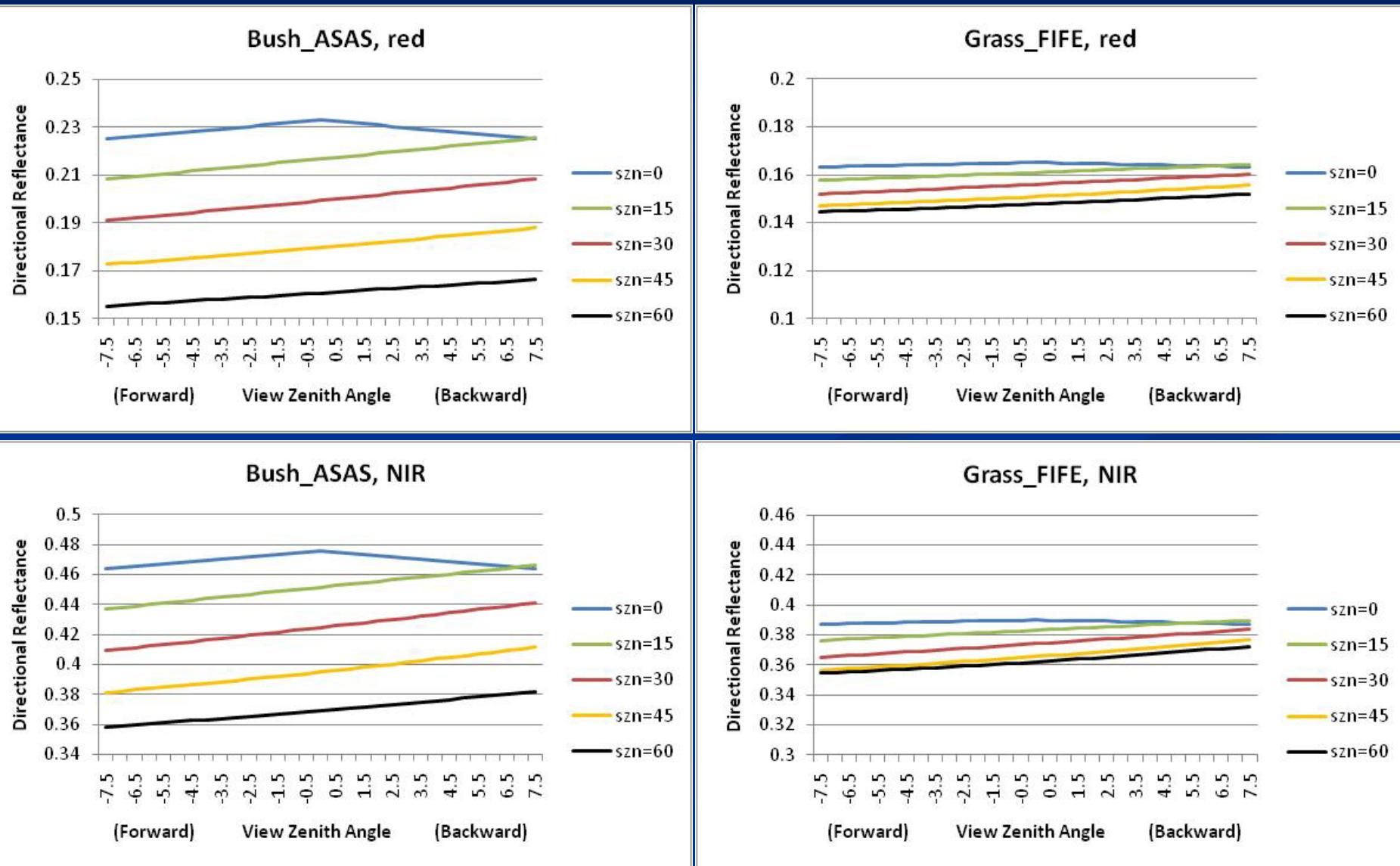
- Input data pairs of fine and coarse spatial resolution need to be adjusted and be consistent before applying data fusion process
  - AVHRR and Landsat data have different band passes, BRDF and phenology (bi-weekly AVHRR vs. daily Landsat) effects etc.
  - Our empirical normalization approach works for AVHRR and Landsat data adjustment
- AVHRR data quality and spatial details are not as good as MODIS data
  - The selection of appropriate input pairs for StarFM data fusion is important.
  - The appropriate input pairs should be cloud free and have a higher correlation for coarse resolution images (AVHRR) between input and prediction date.
- Landsat NDVI time-series based on the fusion approach are generally consistent and reasonable
  - Can be used to produce phenological metrics at Landsat resolution
  - Phenological metrics are useful for environmental monitoring and climate change studies

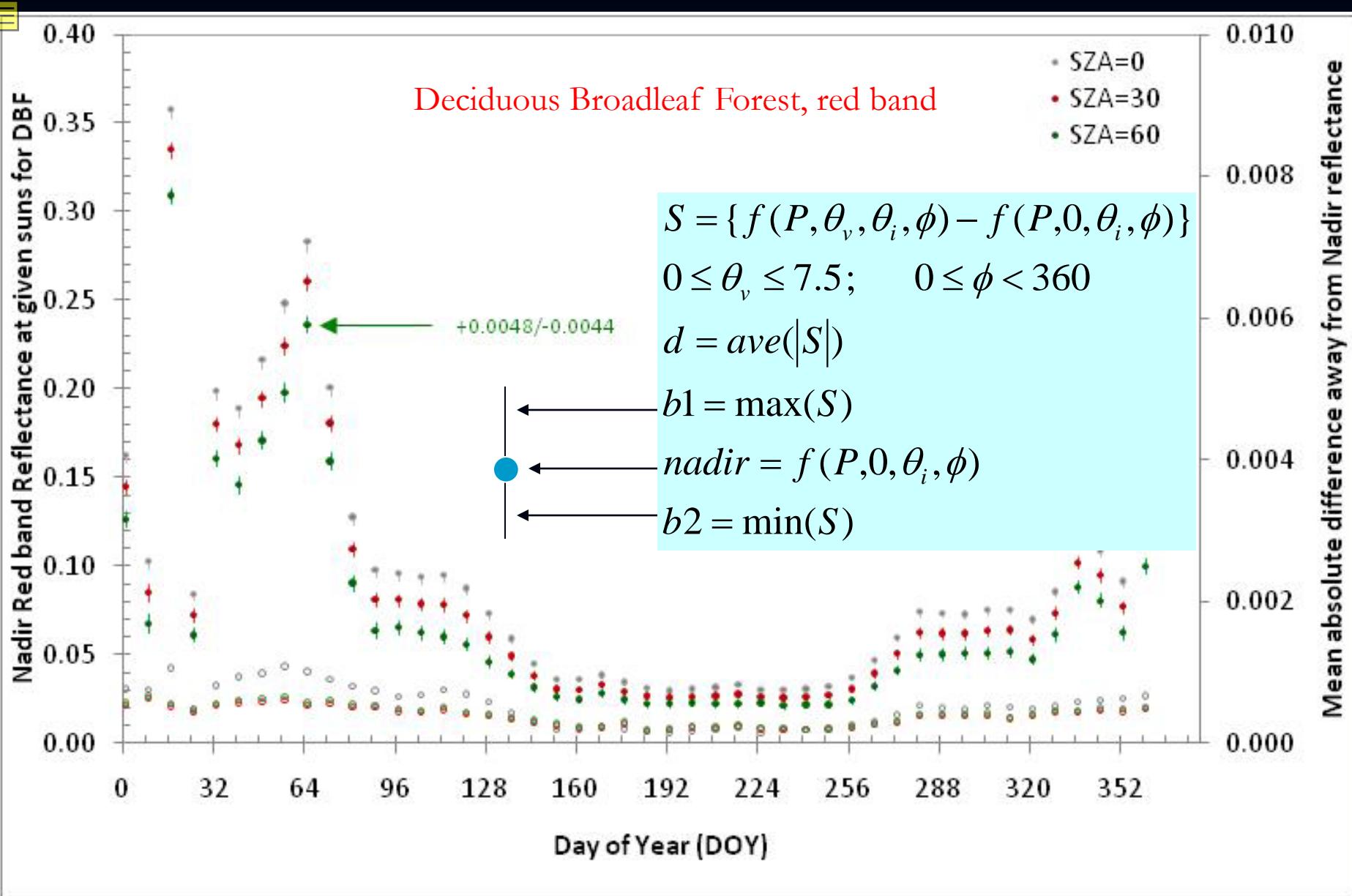
# Part II. Examining Landsat BRDF Effects

- Examine within-scene BRDF effect caused by the changes of viewing geometries (~ $\sim \pm 7.5$  degrees)
- Two test cases
  - Error analysis from samples based on field measurements and MODIS high quality data
  - Landsat simulation tests using MODIS BRDF parameters at Landsat and nadir viewing geometries
- MODIS BRDF model (RossThick-LiSparse-R)

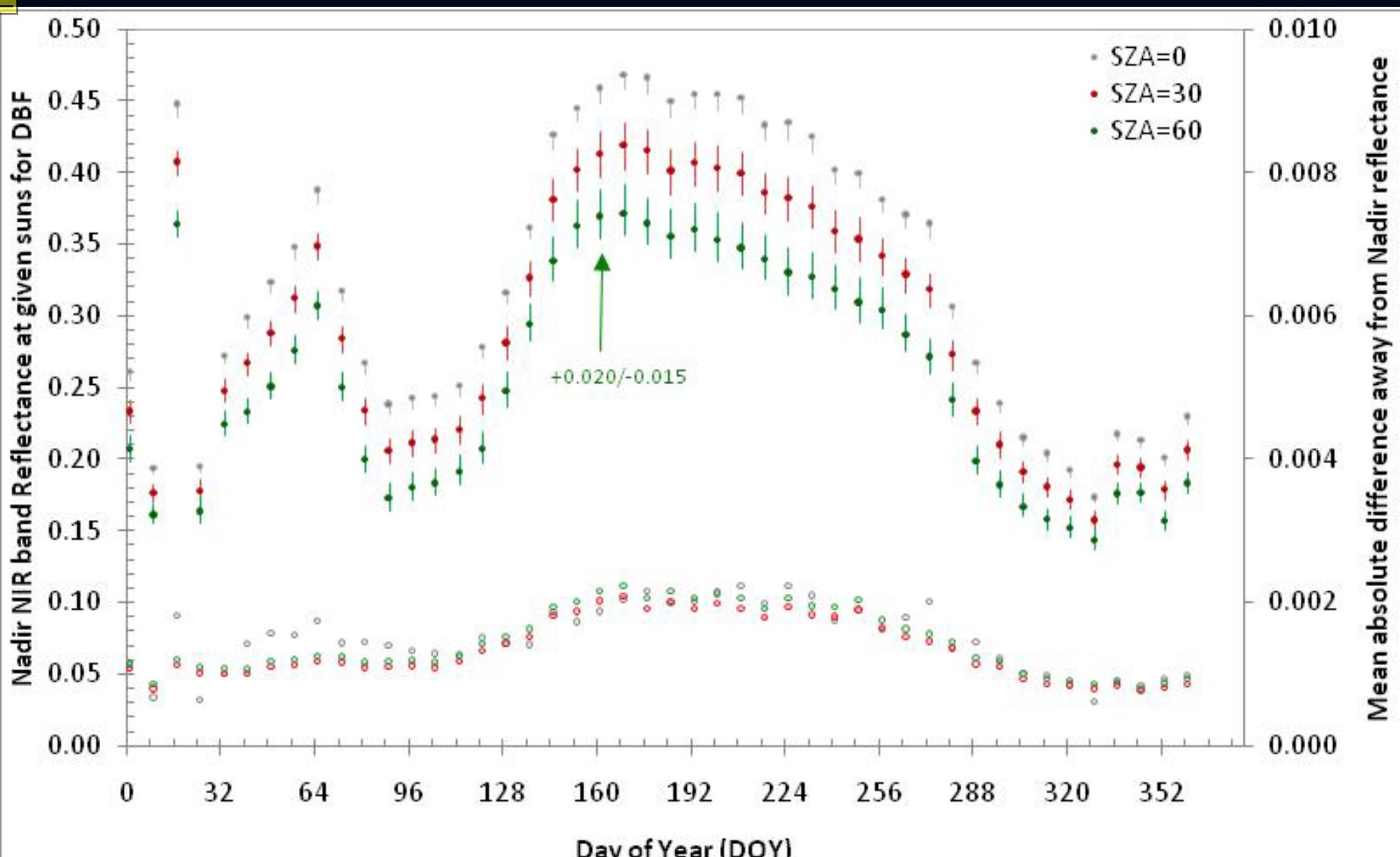


# Bidirectional Reflectance at Principal Plane from Field Measurement

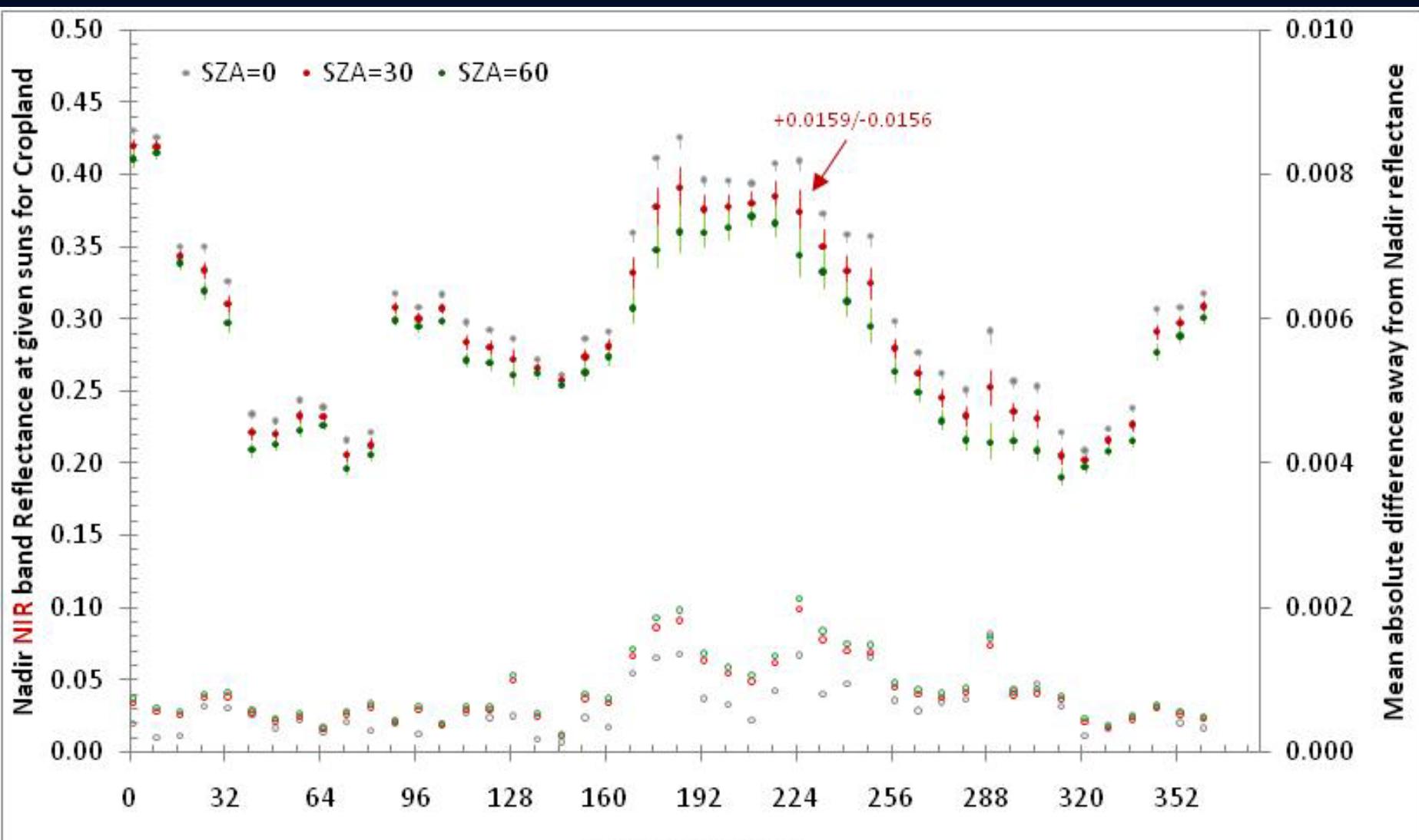




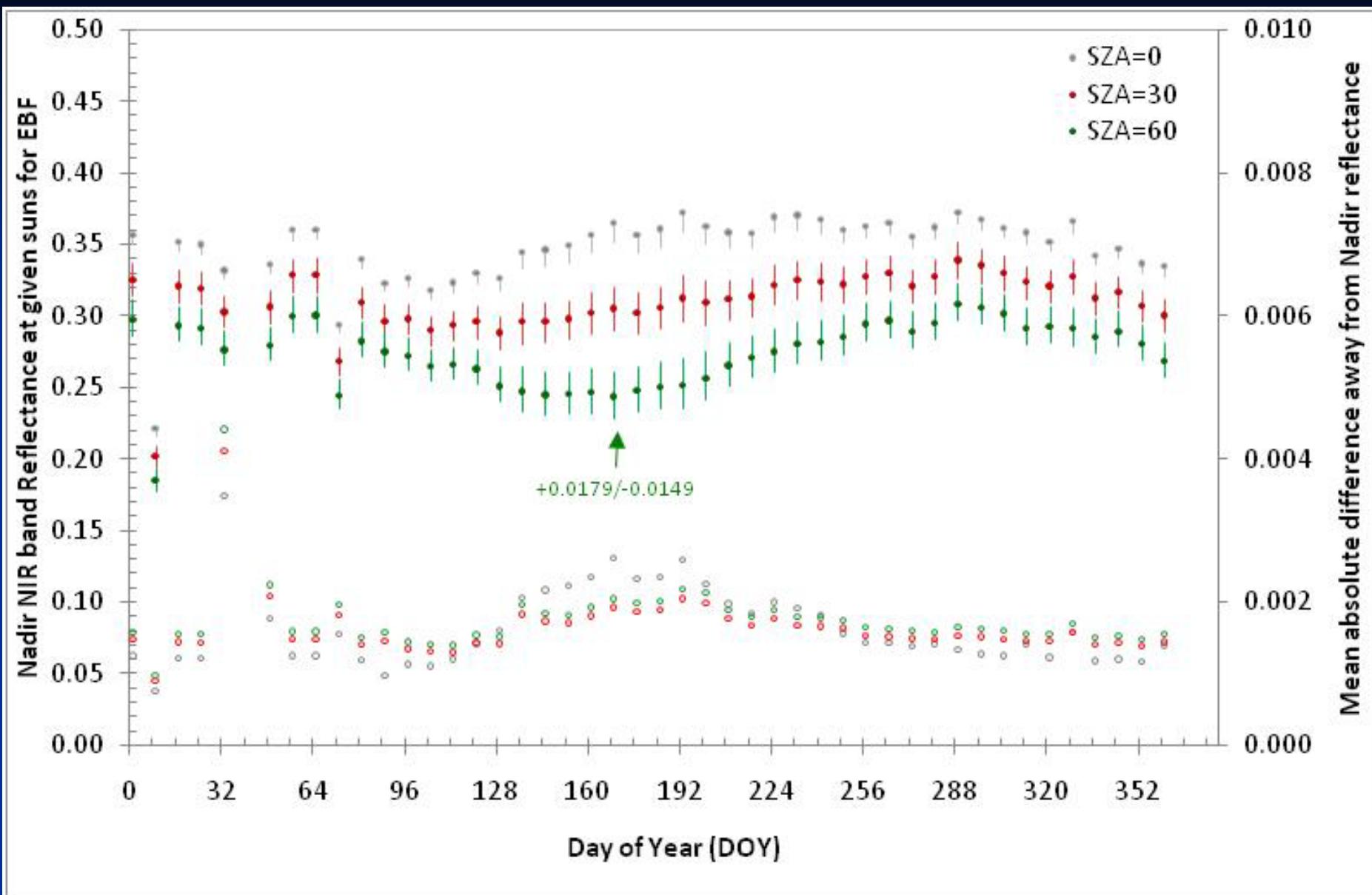
Solid dots are reflectance at nadir view (*nadir*). Error bars show the maximum differences ( $b1$  and  $b2$ ) of bidirectional reflectance (left Y-axis) between nadir view and other views in the whole hemisphere. Circles show mean absolute differences ( $d$ , right Y-axis) within the whole hemisphere



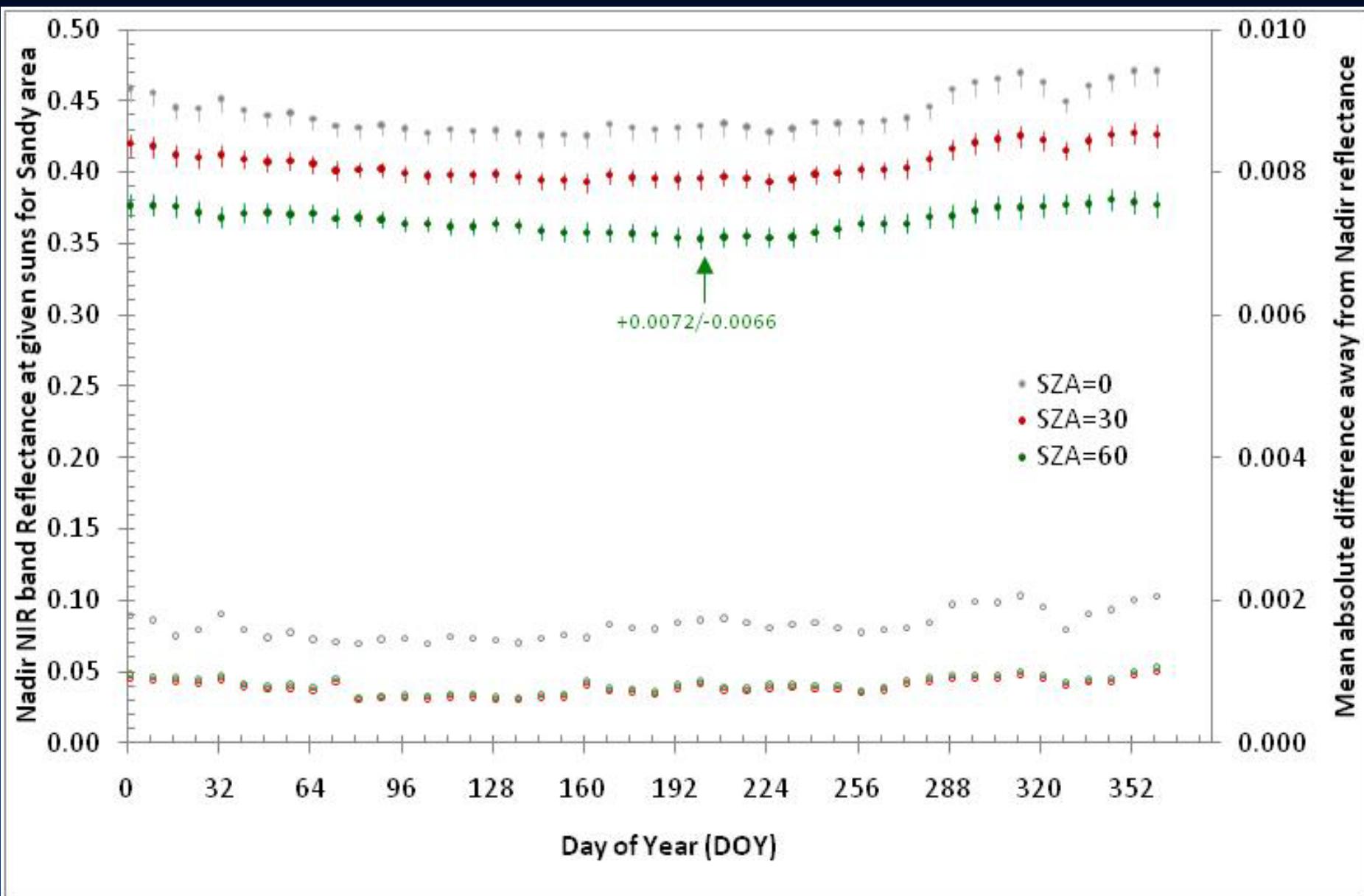
Deciduous Broadleaf Forest, NIR band



Cropland, NIR band



Evergreen Broadleaf Forest, NIR band



Sand, NIR band

# Landsat BRDF Simulation Test

WRS-2  
Path / Row: 12 31 Go

Lat: 41.8 Long: -71.4 Go

Max Cloud: 100% Up Down

**Scene Information:**  
ID: LE70120312002212EDC00  
Cloud Cover: 0% Qty: 9  
Date: 2002/7/31

Jul 2002 Go

Prev Scene Next Scene

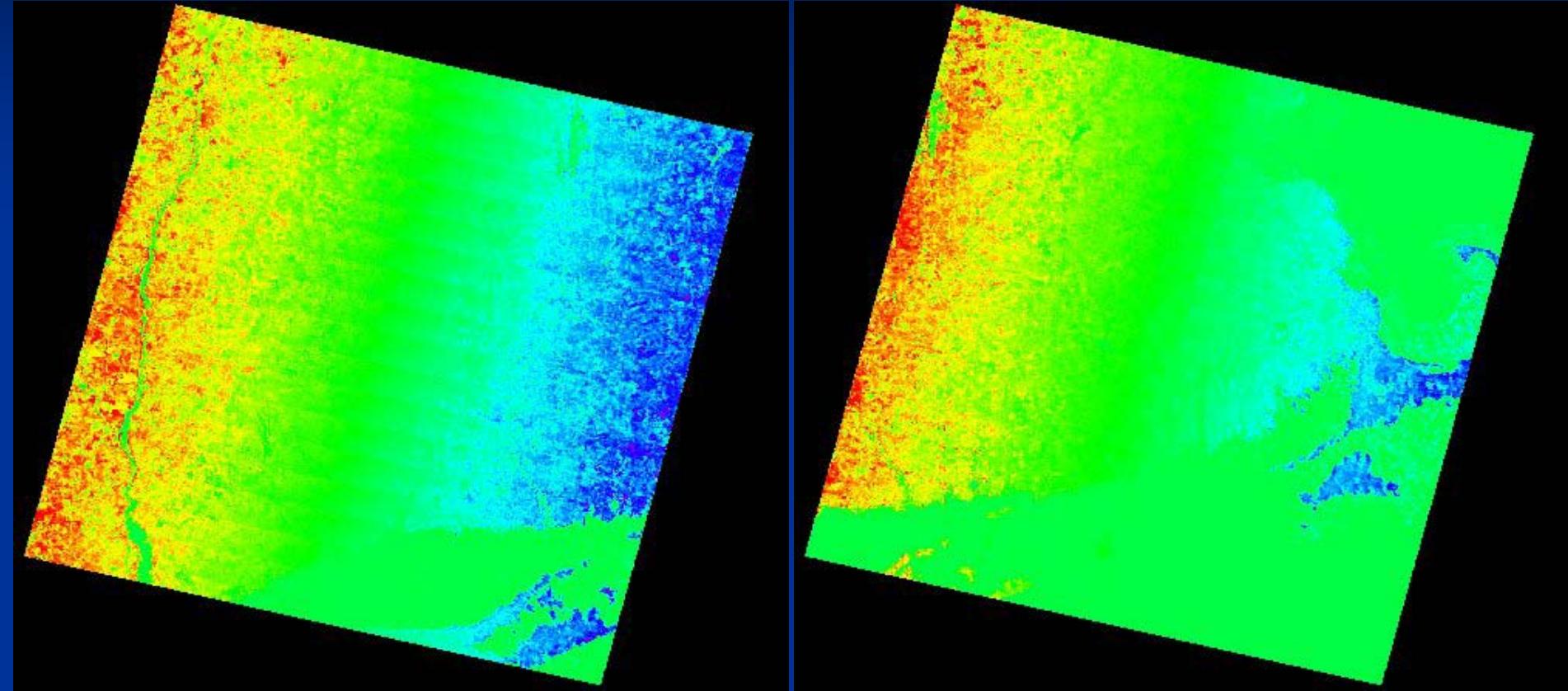
**L7 SLC-on (1999-2003) List**

- LE70120312002212EDC00
- LE70130312002251EDC00

Add Del Submit Download

**USGS**

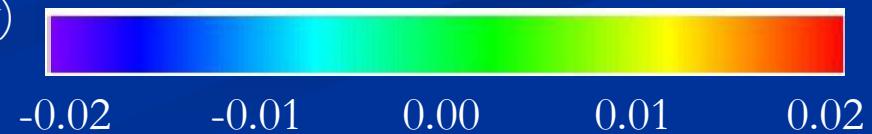
# Difference between the simulated Landsat and nadir reflectance (NIR)



p13r31

p12r31

Simulated\_Landsat =  $f(\text{MODIS\_BRDF}, \text{Landat\_view})$   
Simulated\_Nadir =  $f(\text{MODIS\_BRDF}, \text{Nadir\_view})$   
(both use same solar angles)

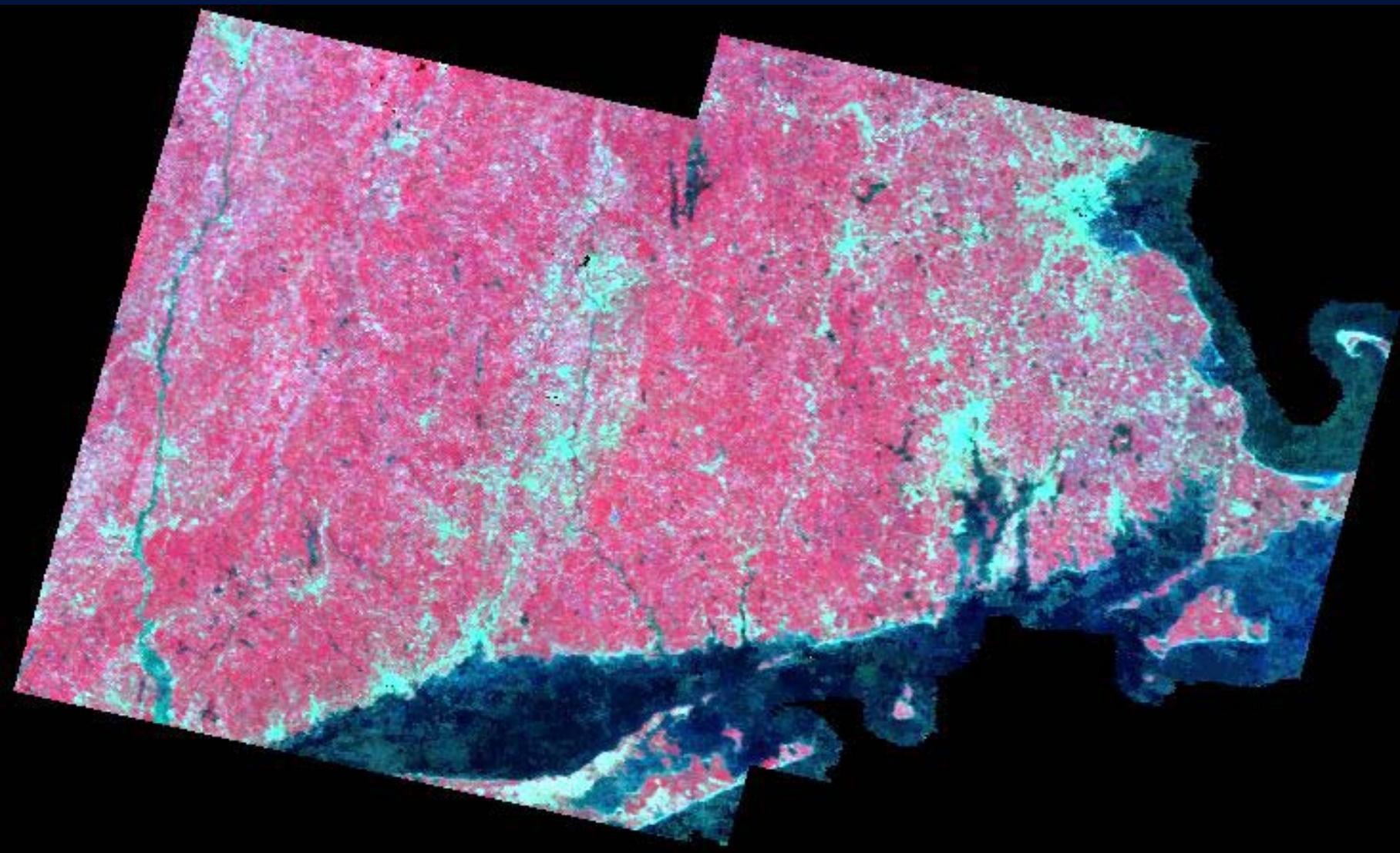




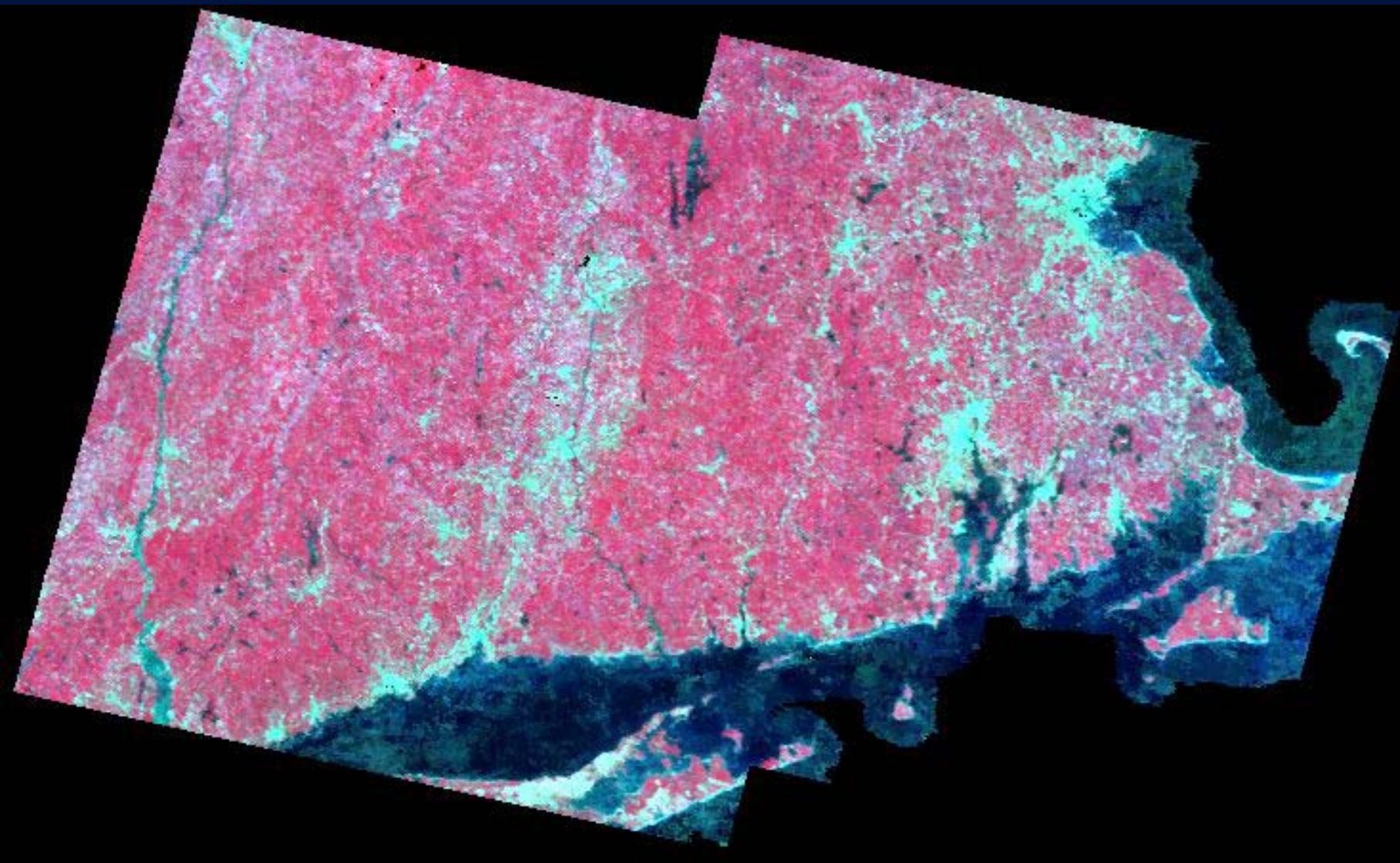
Mosaic of the simulated Landsat reflectance from MODIS BRDF product (2005-193) at Landsat viewing geometries (red, green and blue bands in RGB composite)



Mosaic of the simulated nadir reflectance from MODIS BRDF product (2005-193) at nadir viewing geometries (same illumination geometries as the simulated Landsat)

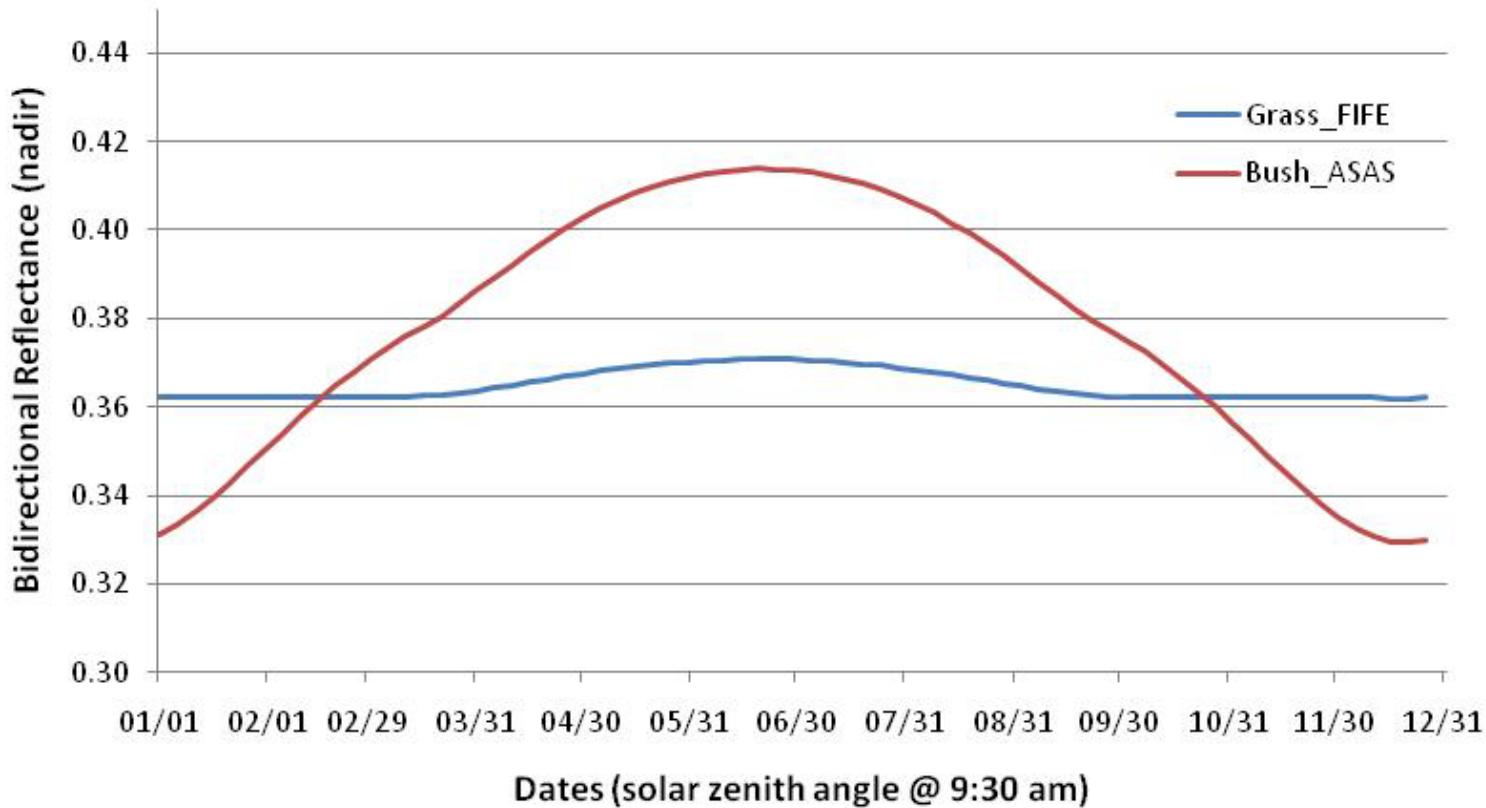


Mosaic of the simulated Landsat reflectance from MODIS BRDF product (2005-193) at Landsat viewing geometries (NIR, red and green bands in RGB composite)



Mosaic of the simulated nadir reflectance from MODIS BRDF product (2005-193) at nadir viewing geometries (same illumination geometries as the simulated Landsat)

## Fixed BRDF Parameters, Nadir View BRF

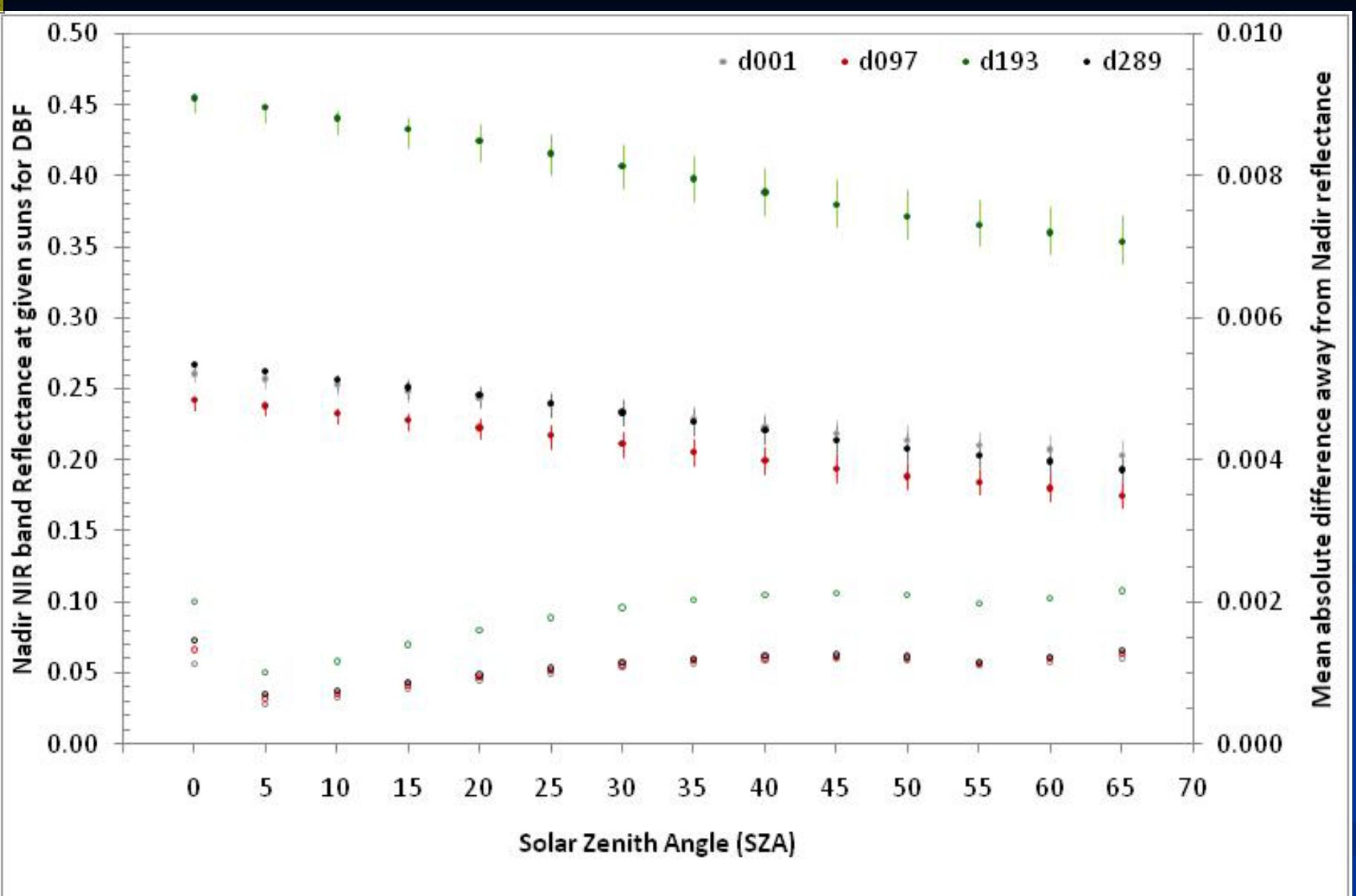


Reflectances vary with different acquisition dates (solar zenith angle) using fixed BRDF parameters at nadir view

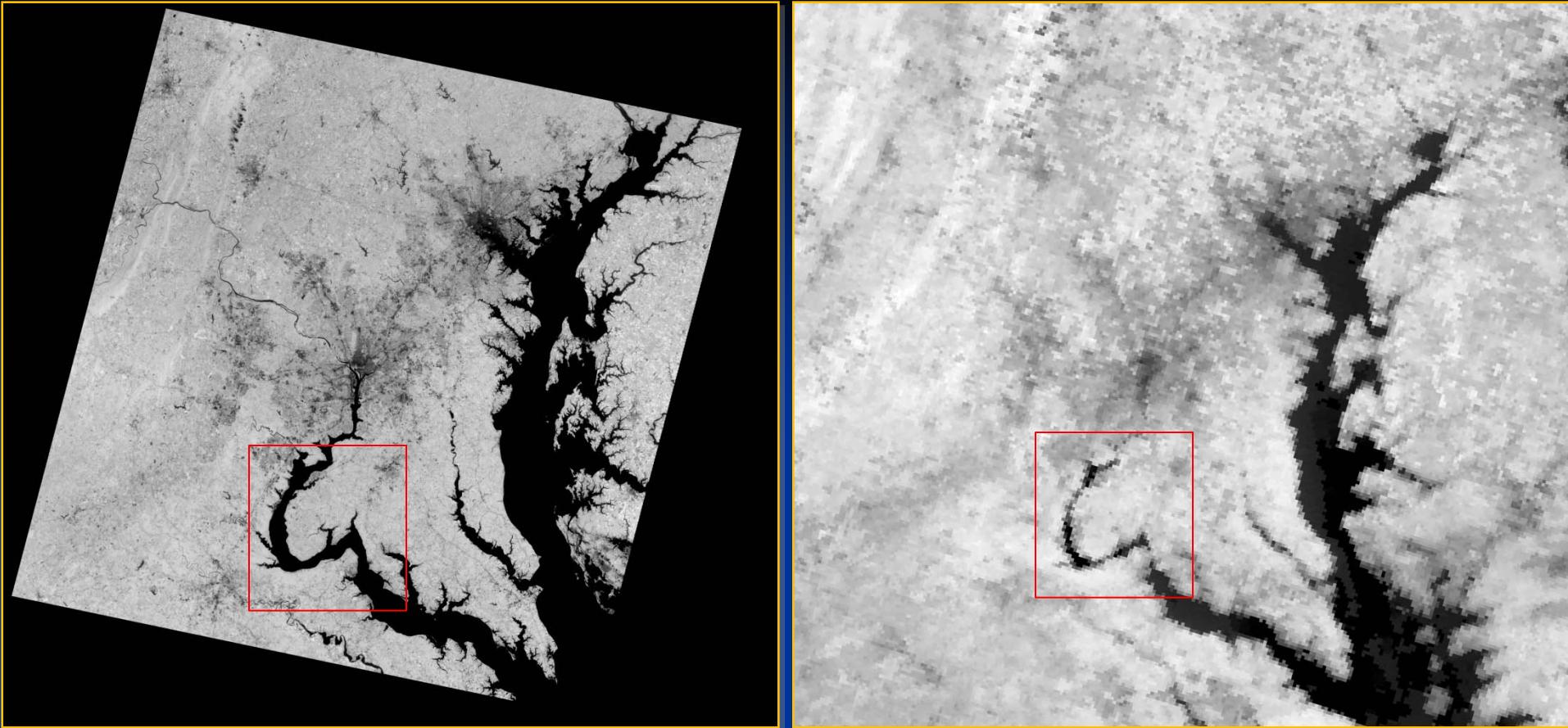
# Conclusion

- Within a Landsat scene, the maximum variations caused by the change of viewing angles are about +-3% reflectance (absolute) for NIR band and +-1% for visible bands in our case study
- Within-scene variations caused by viewing angles is much smaller than variations caused by solar angles change (acquisition dates) and seasonal phenology changes
- BRDF effect is not obvious visually from mosaics, but noticeable when comparing to the nadir viewing reflectance
- Depending on applications, correction on the BRDF effect may be needed
- Next, correction approach?

# Backup Slides



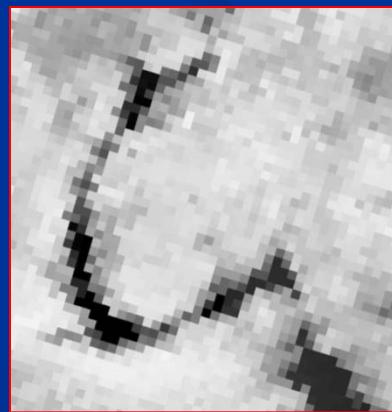
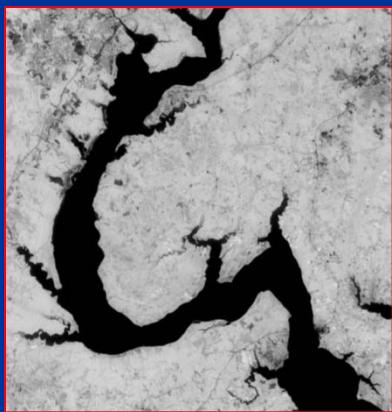
BRDF parameters are extracted from MODIS BRDF products for four dates (1, 97, 193, 289)



## NDVI PAIR 2

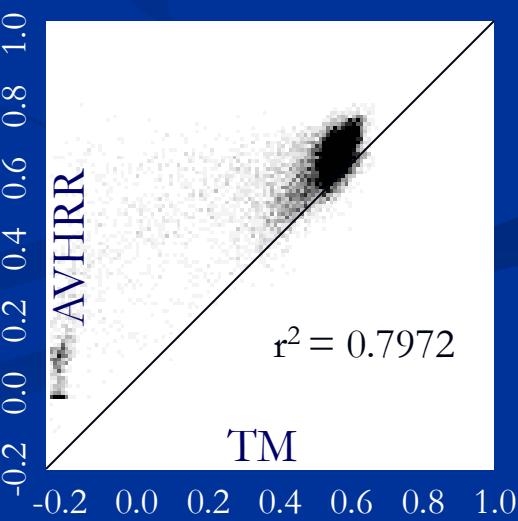
TM: 224  
(8/12)

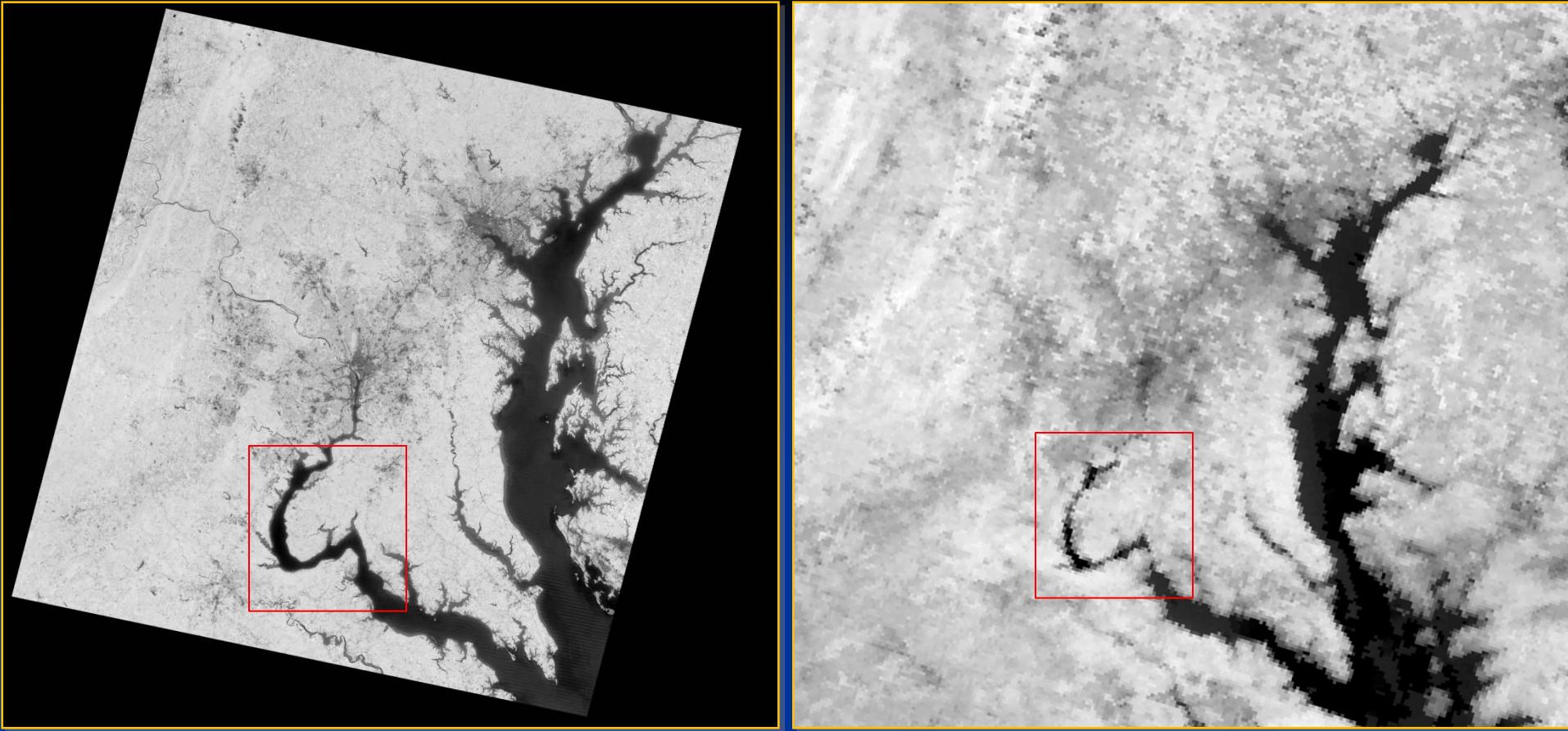
AVHRR: 215-228  
(8/3 – 8/16)



0.0 0.2 0.4 0.6 0.8

0.0 0.2 0.4 0.6 0.8

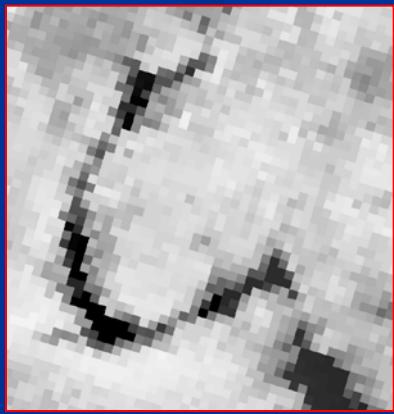




**Adjusted NDVI  
Pair 2**

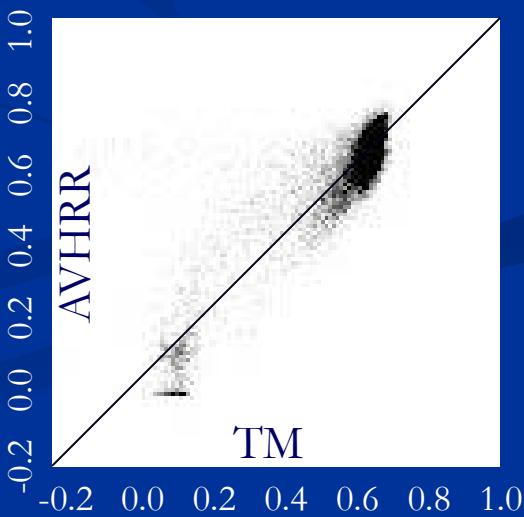
TM: 224 (8/12)

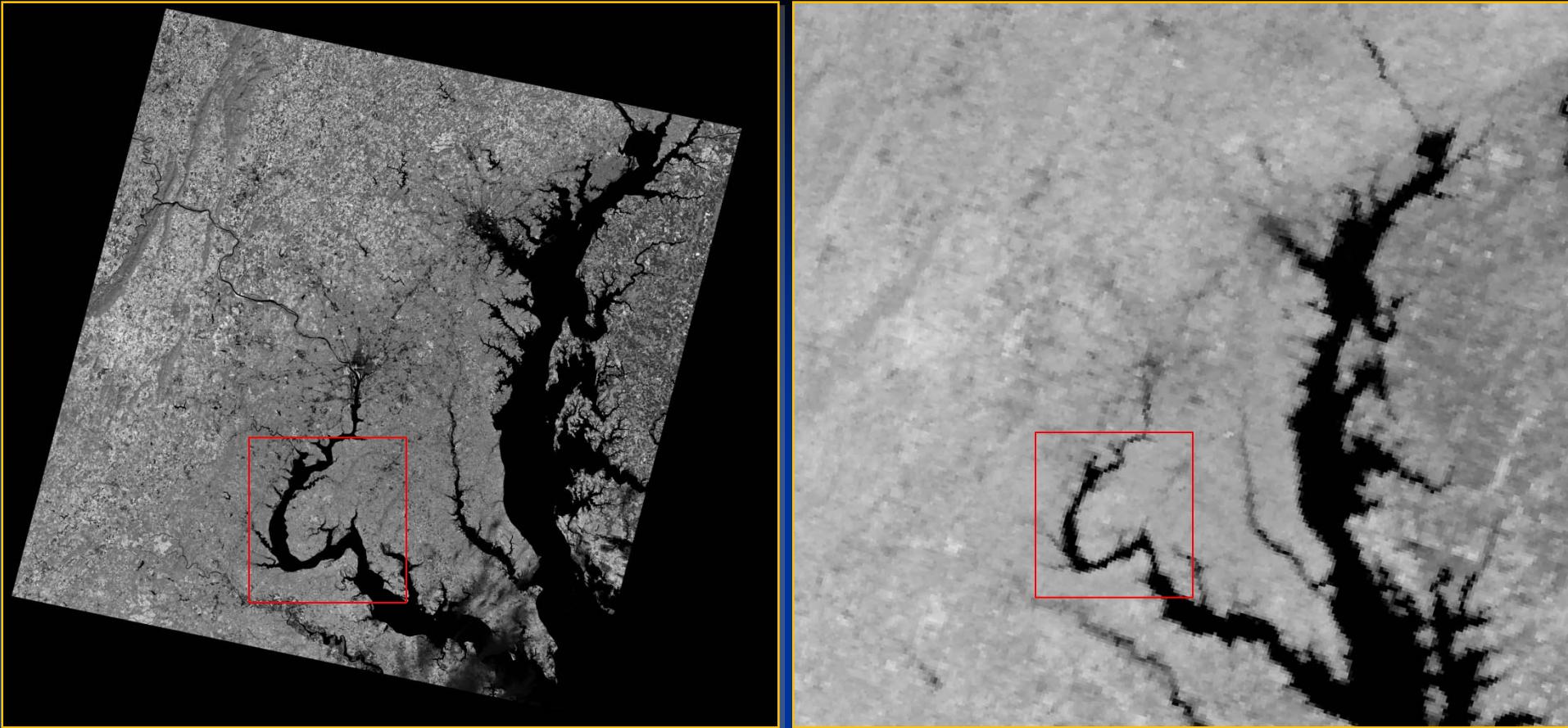
AVHRR: 215-228  
(8/3 – 8/16)



0.0 0.2 0.4 0.6 0.8

0.6 0.8

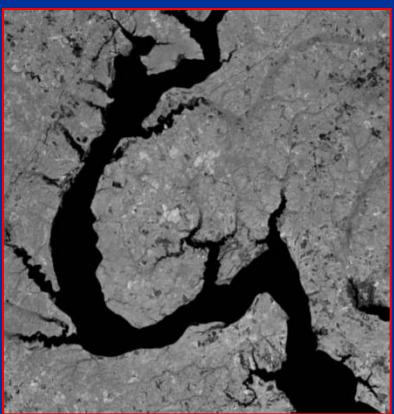




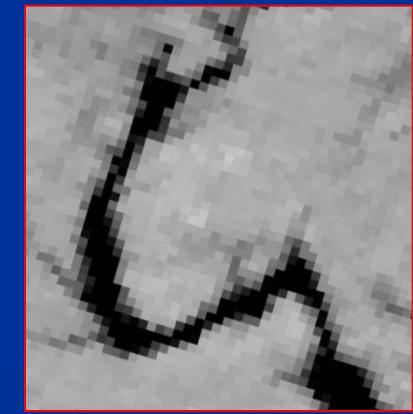
## NDVI PAIR 4

TM: 320  
(11/16)

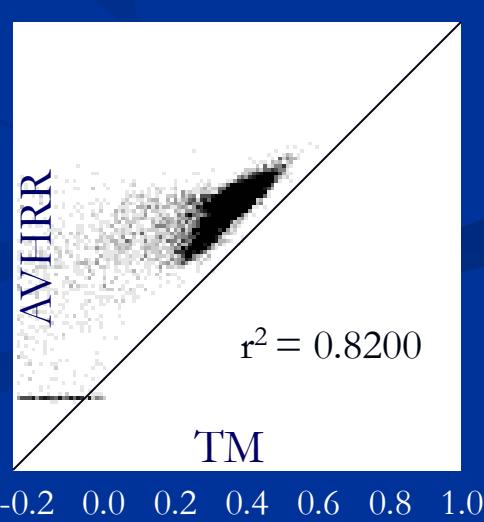
AVHRR: 313-326  
(11/9 – 11/22)

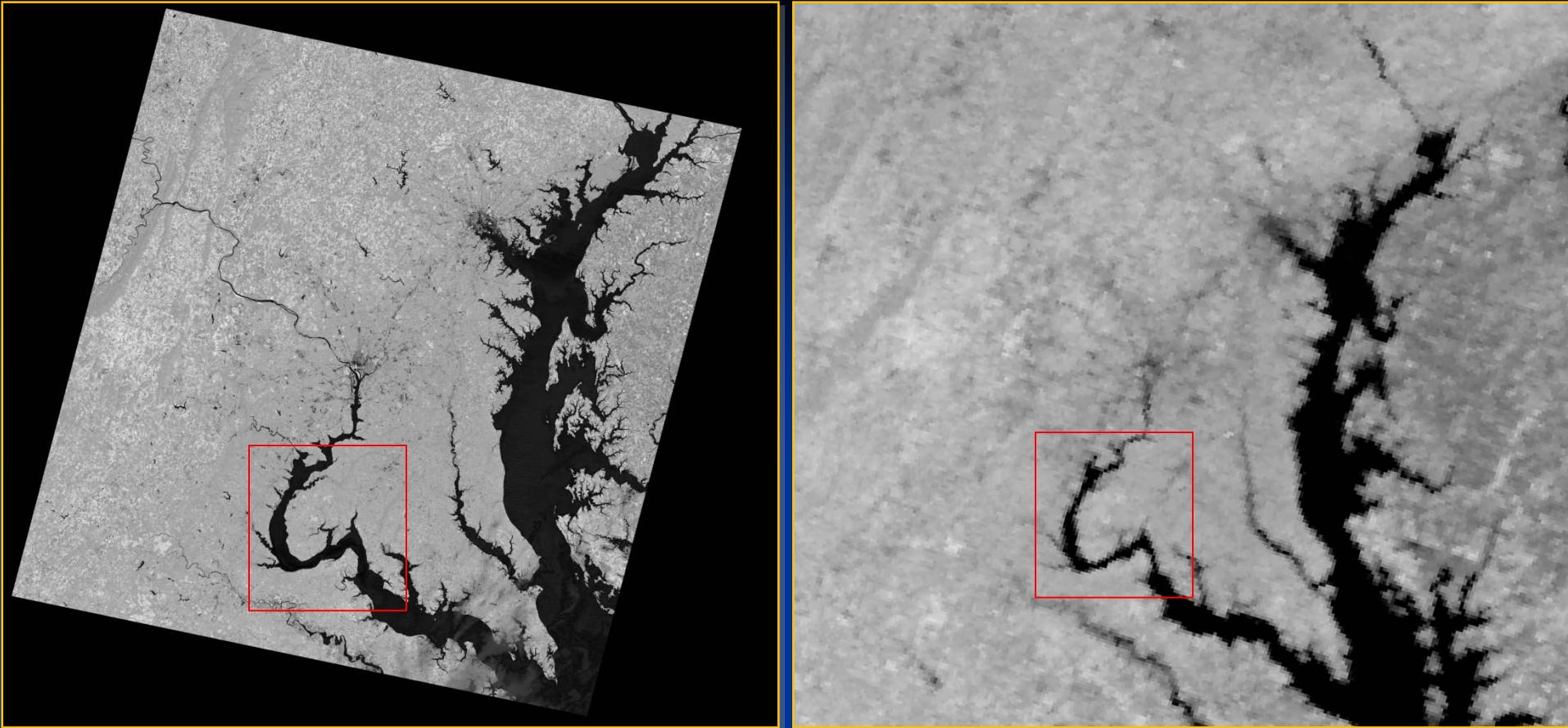


0.0 0.2 0.4 0.6 0.8



0.0 0.2 0.4 0.6 0.8

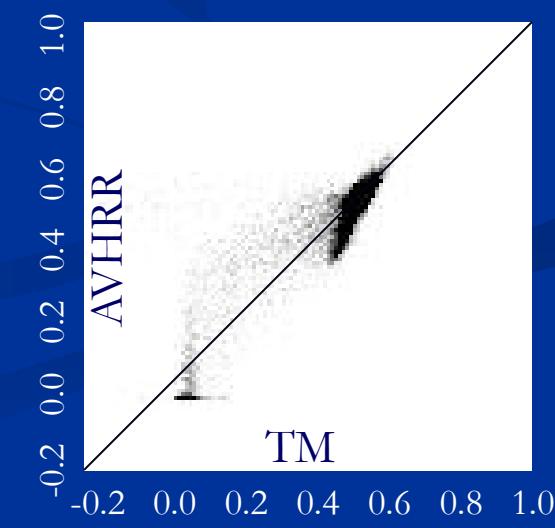
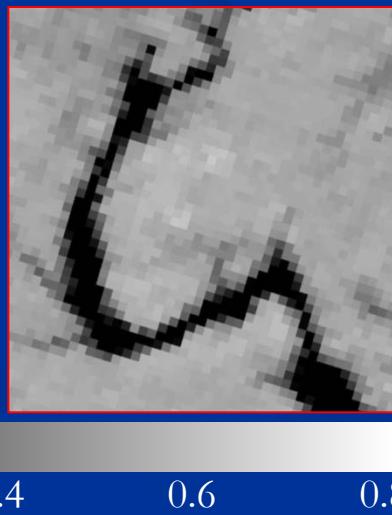




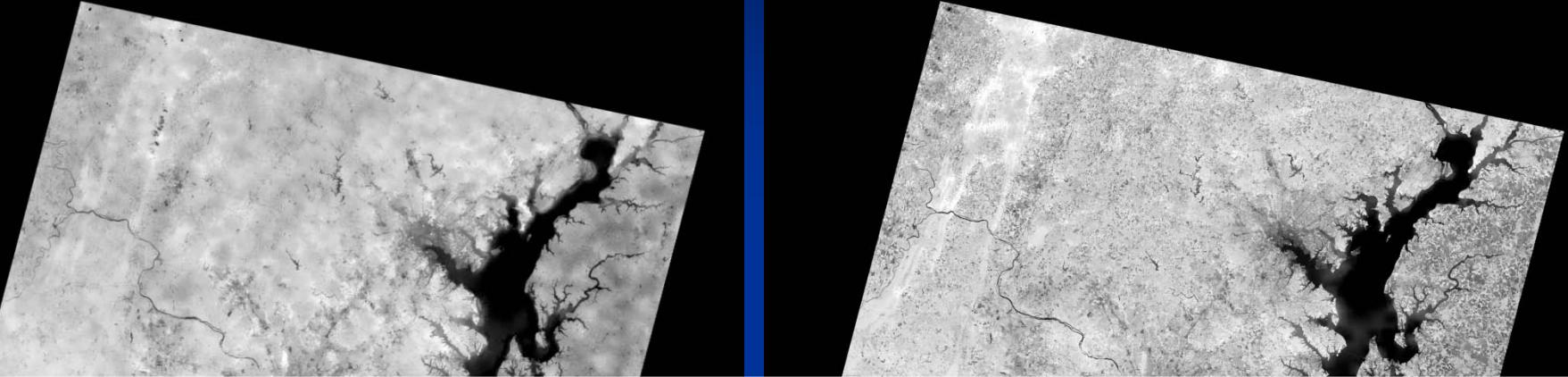
## Adjusted NDVI Pair 4

TM: 320 (11/16)

AVHRR: 313-326  
(11/9 – 11/22)



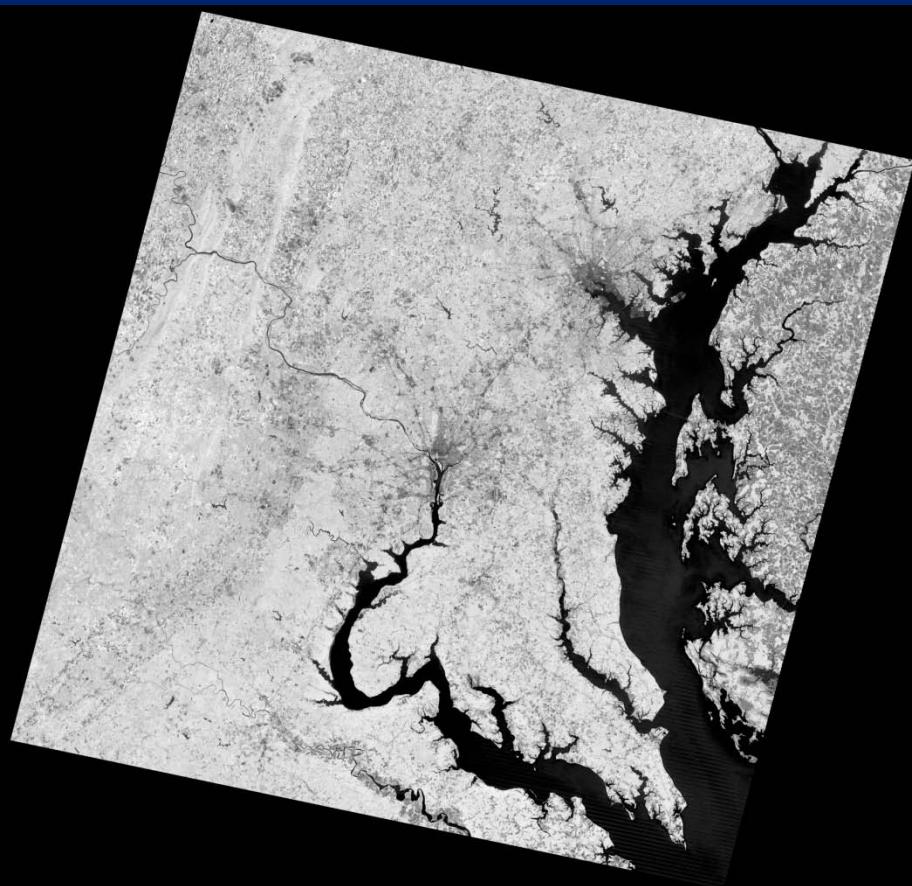
# Different Input Pairs for Day 288 Prediction



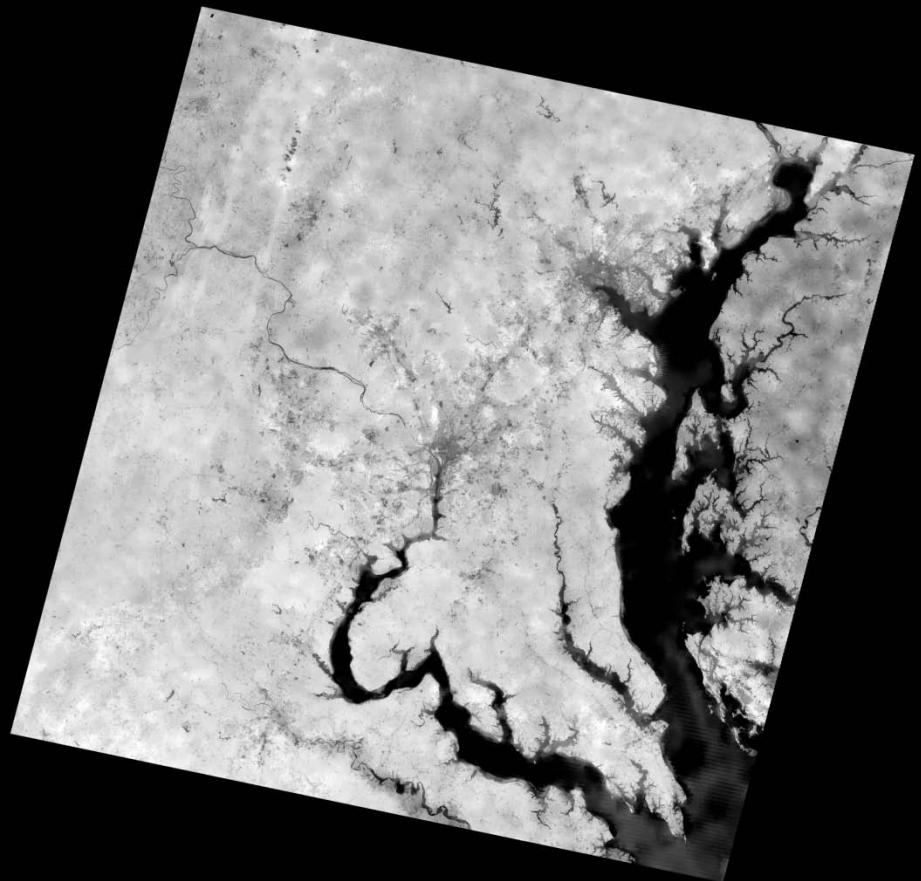
Validation Dates	Averaged Difference (60m)		Averaged Absolute Difference (60m)		Correlation (1km)	Scattering Plot (1km)	
	Input	Predict	Input	Predict		Input	Predict
1990-288 (use 224)	0.036 (0.022*)	-0.004 (-0.002*)	0.075 (0.066*)	0.073 (0.065*)	0.880		
1990-288 (use 128)	-0.003 (0.007*)	0.002 (0.002*)	0.064 (0.061*)	0.058 (0.048*)	0.917		

(\* land pixels only)

# Result for 1990-288

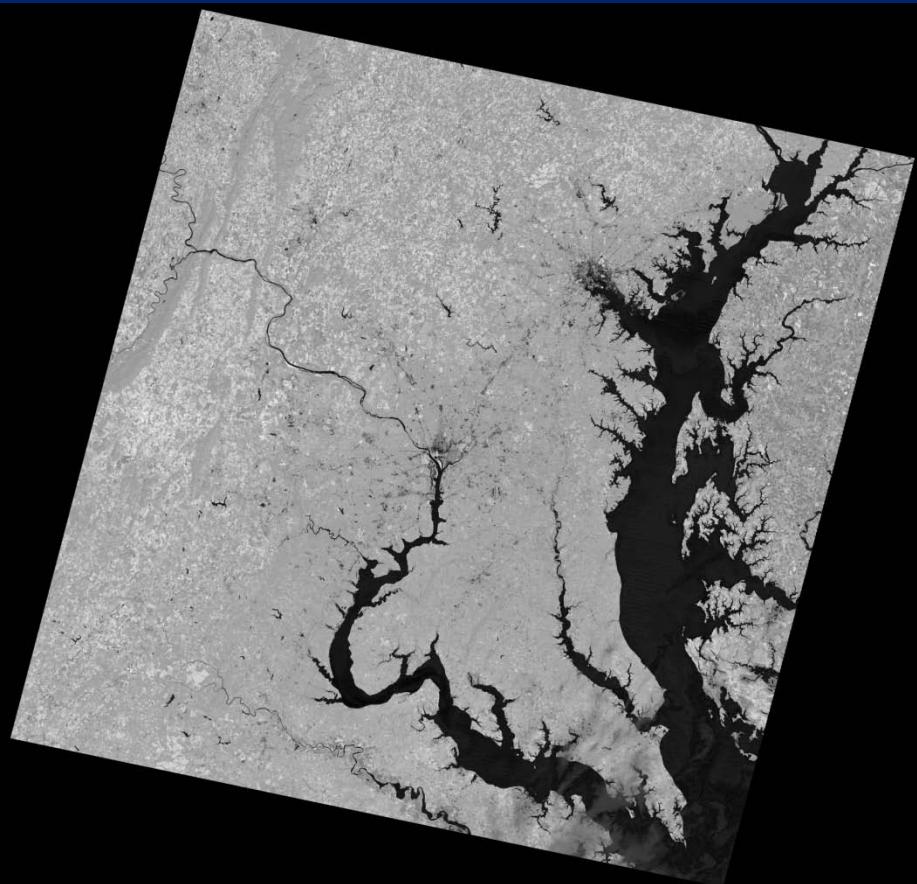


Landsat adjusted NDVI

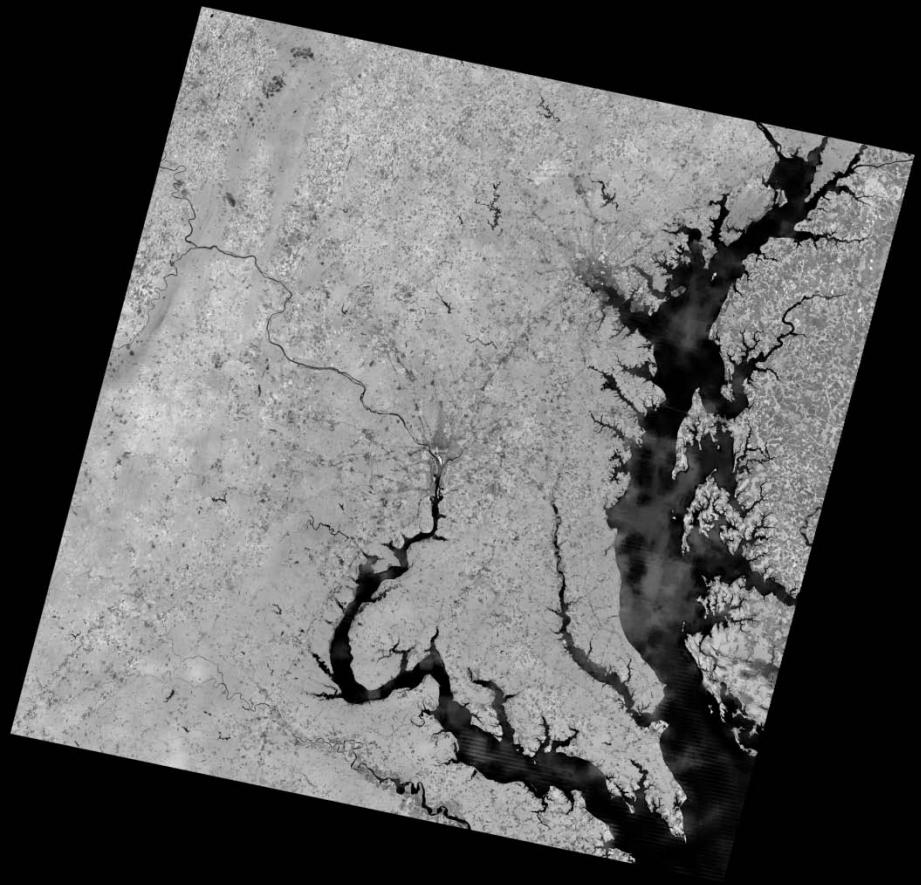


Predicted NDVI used 224

# Result for 1990-320



Landsat adjusted NDVI



Predicted NDVI using 288