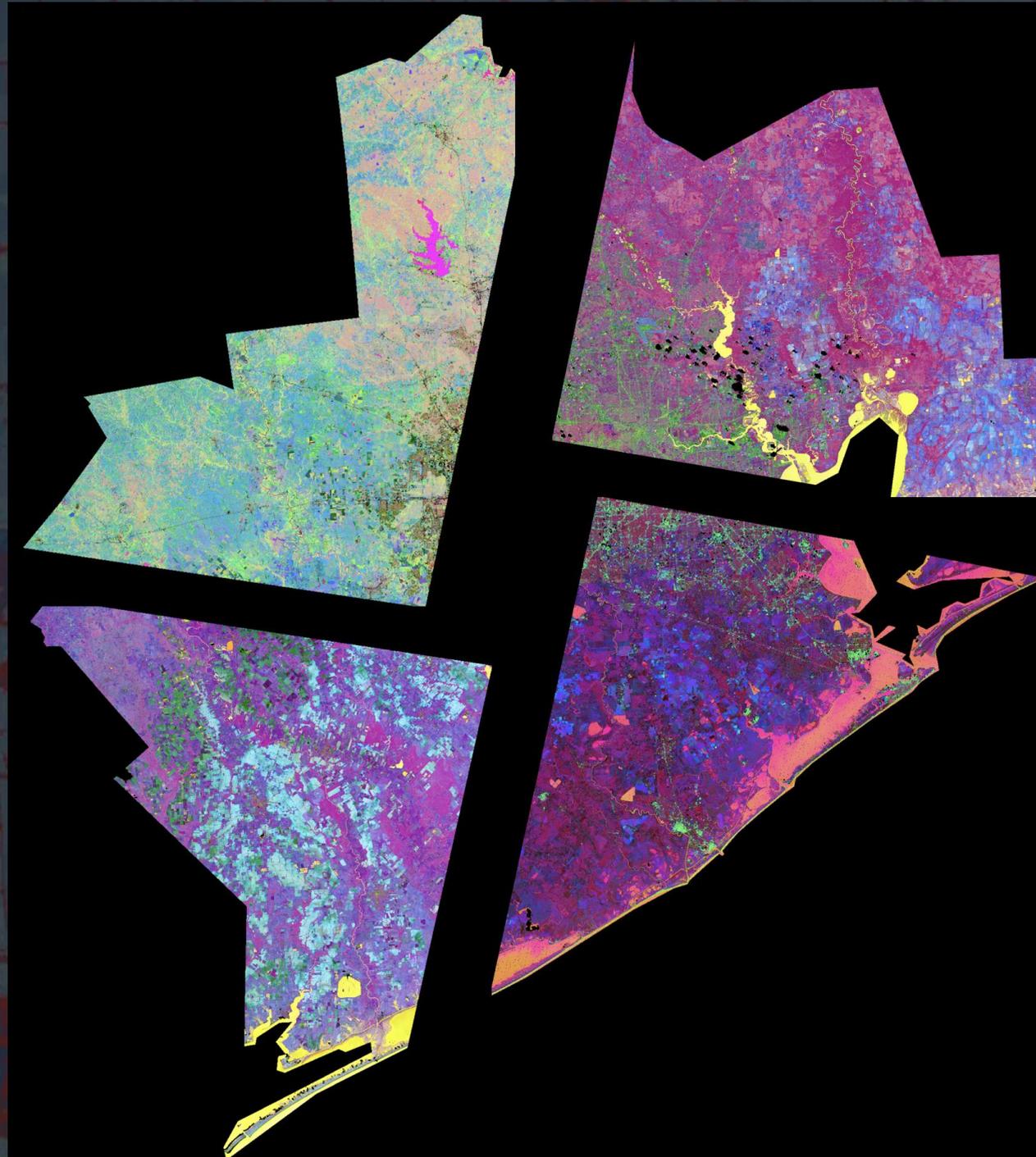


Subannual mapping of impervious surface in the Houston metropolitan area



Christopher R. Hakkenberg
Postdoctoral Scholar (GEODE lab)
2019-9-23

HOUSTON IS ONE OF THE FASTEST GROWING CITIES IN THE NATION



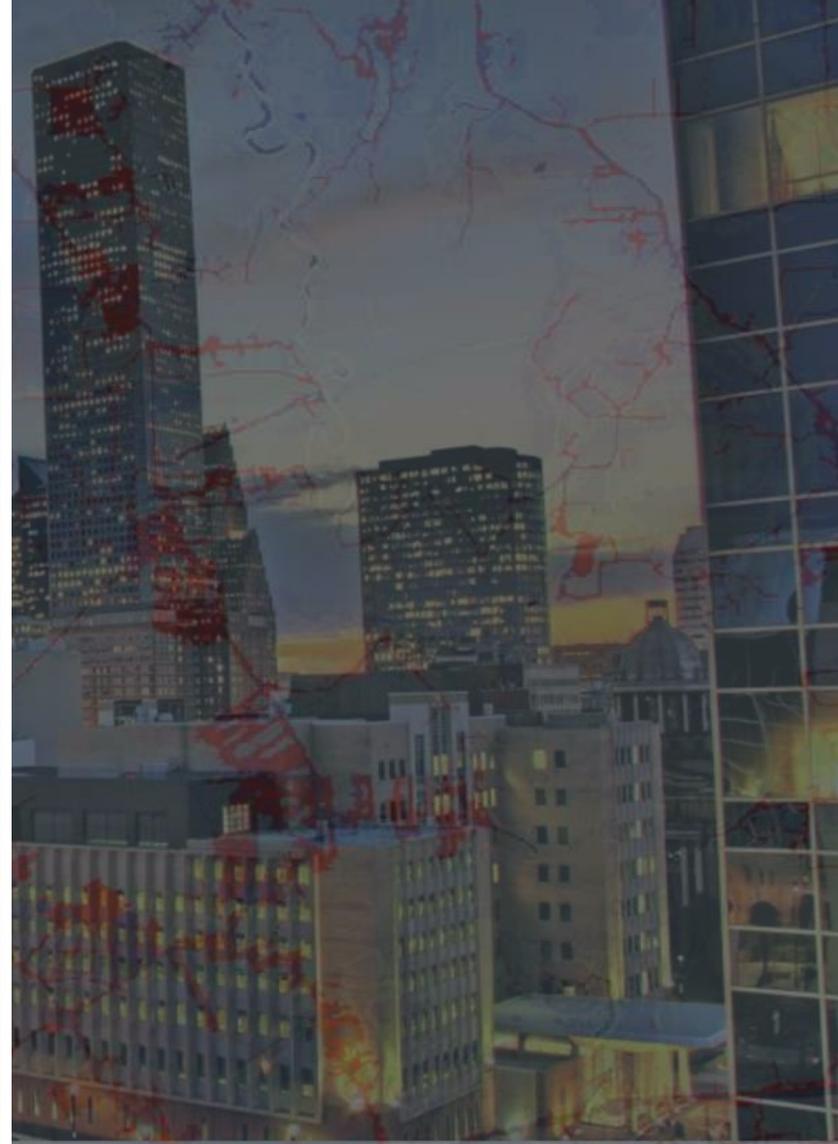
HOUSTON'S POPULATION IS ON THE RISE AND THE AREA IS CONTINUALLY GROWING TO ADAPT TO THEIR NEW RESIDENTS.

Los Angeles Times

How Houston has become the most diverse place in America



T GROWING CITIES IN



HOUSTON'S POPULATION IS ON THE RISE AND THE AREA IS CONTINUALLY GROWING TO ADAPT TO THEIR NEW RESIDENTS.

Los Angeles Times
HOUSTON IS ONE

How Houston has become the most diverse
place in America



HOUSTON'S POPULATION IS
CONTINUALLY GROWING TO ADAPT TO THEIR NEW RESIDENTS.

From Space City to Food City: In 2019, Houston's brand is all about delicious diversity

Alison Cook and Greg Morago | March 26, 2019 | Updated: March 26, 2019 6:25 p.m.



Houston Is the New Capital Of Southern Cool

By Brett Martin • August 23, 2018

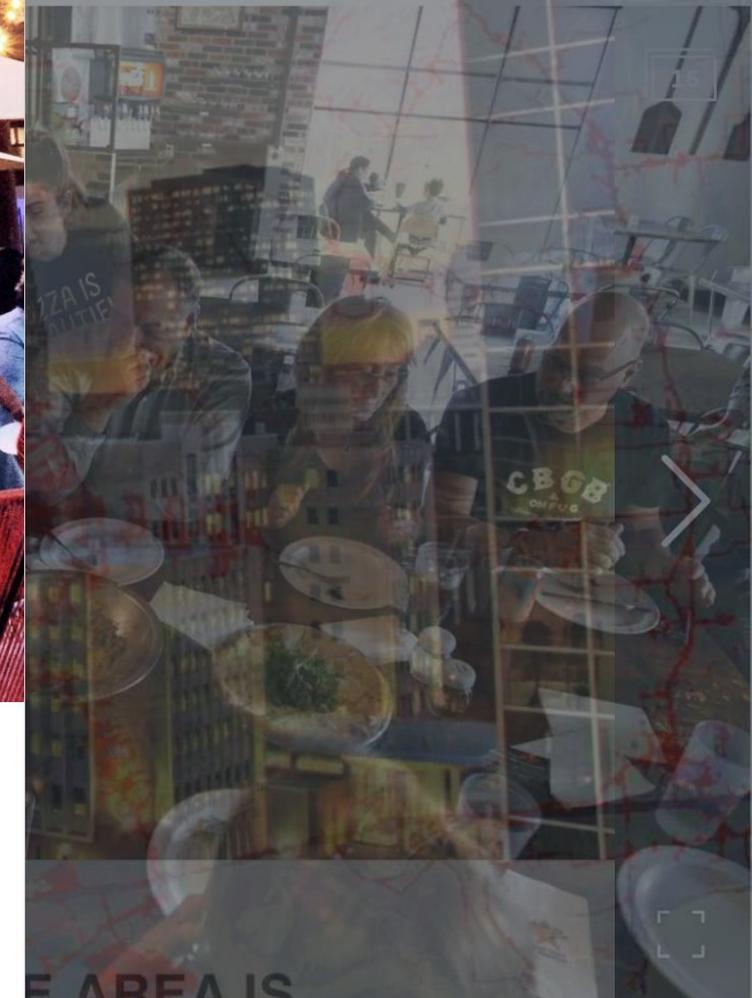


The casual outdoor vibes at the Axelrad Beer Garden.

A few years ago, Matthew Odam was driving from Austin, Texas, where he's the restaurant critic at the *Austin American-Statesman*, to Houston, where he was raised. He had a passenger: a friend of a friend who was moving back to Houston after spending some time kicking around the capital, working music

...IVING CITIES IN
to Food City:
's brand is all
diversity

...d: March 26, 2019 6:25 p.m.



...E AREA IS
CONTINUALLY GROWING TO ADAPT TO THEIR NEW RESIDENTS.

5 min ago

George Bush Intercontinental Airport got half a foot of rain in two hours

From CNN Meteorologist Allison Chinchar

As of noon ET (11 a.m. CT), George Bush Intercontinental Airport in Houston has received 6.42 inches of rain in two hours. The airport averages 4.07 inches of rain for the entire month of September.

Their September monthly record is 13.37 inches set back in 1913.

Government Business Safety

Brian K. Sullivan and Catherine Ngai | Bloomberg News September 20, 2019 11:15 AM, EDT

Imelda Rainfall Totals Almost 4 Feet in Houston



USPS delivery truck navigates low water in Houston. (David J. Phillip/Bloomberg News)

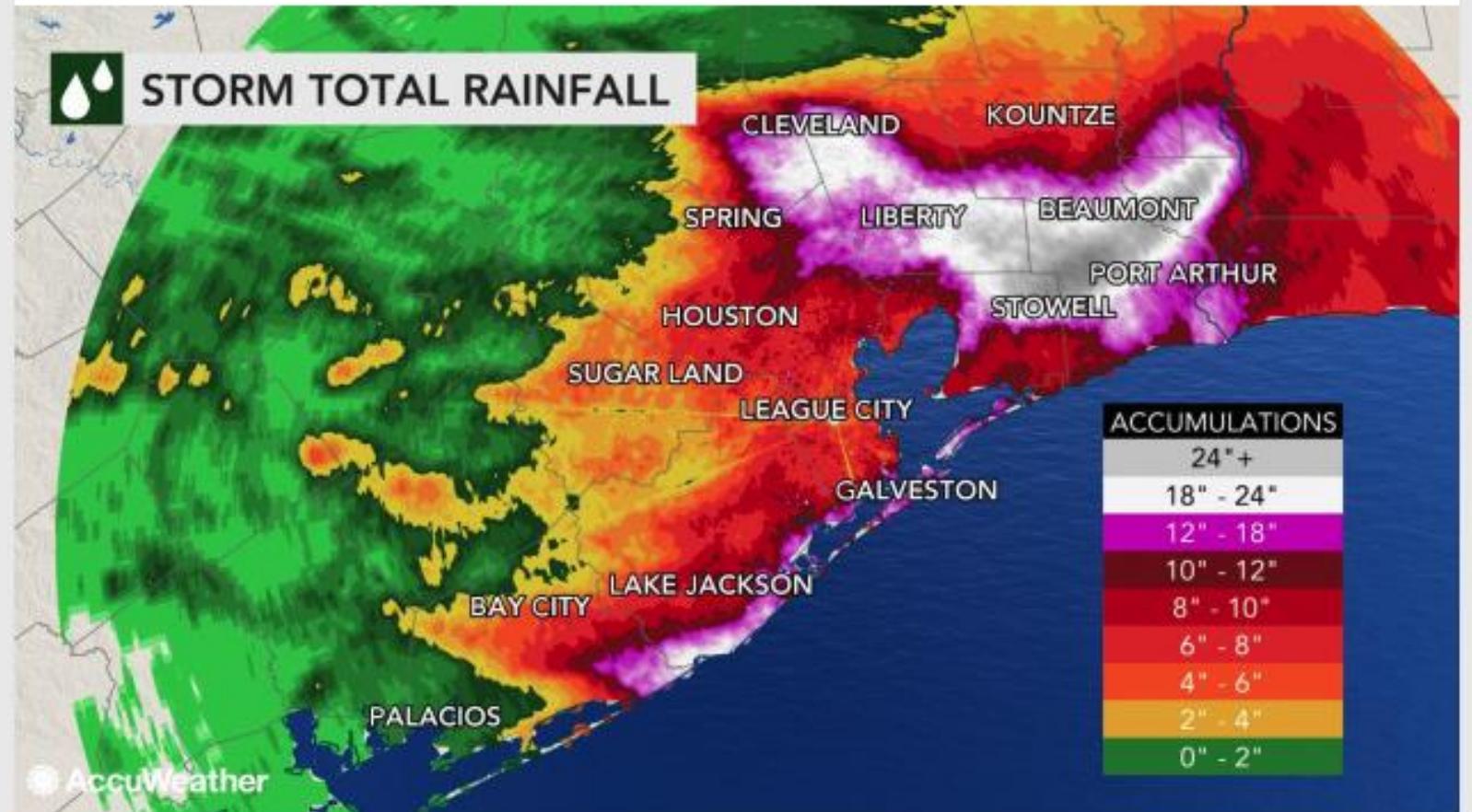
CNN US Crime + Justice Energy + Environment Extreme Weather Space + Science

Rescues are underway as Imelda floods roads and homes in southeastern Texas

By Jason Hanna, Gianluca Mezzofiore and Madeline Holcombe, CNN
Updated 11:47 AM ET, Thu September 19, 2019

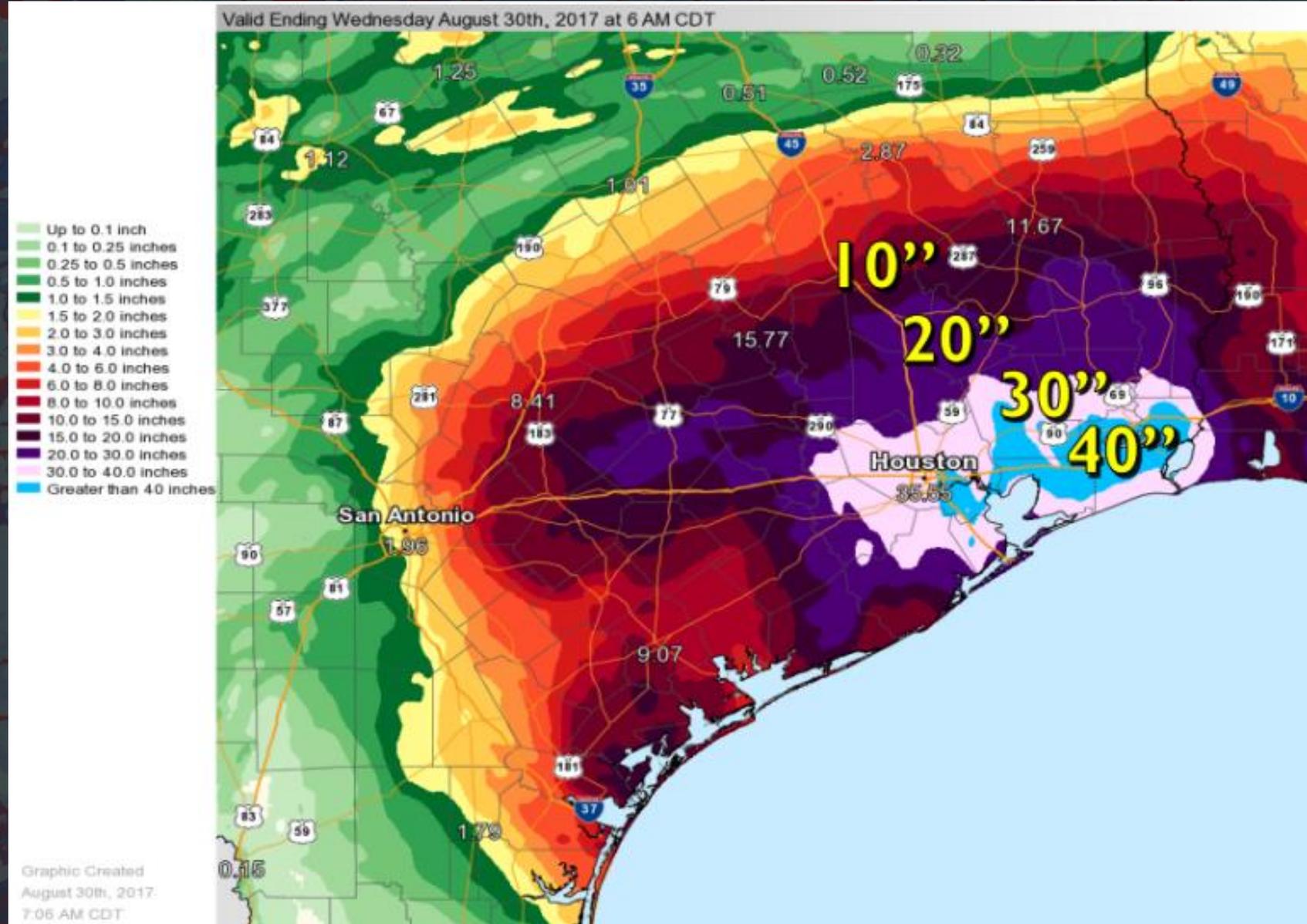


More from CNN



The latest rainfall reports from Imelda as of 9 a.m. CDT Friday, Sept. 20.

Hurricane Harvey (August 2017)



5 Day Point Rainfall Amounts in Inches

- Harvey continued to produce record breaking **rainfall totals** of **45 to over 50 inches**... with continued rainfall
- **Cedar Bayou - 51.88**
- **Berry Bayou - 44.88**
- **League City - 49.84**
- **Mary's Creek - 49.80**
- **Goose Creek - 44.08**
- **Greens Bayou - 41.36**
- **Buffalo Bayou - 35.60**
- **Addicks Dam - 33.44**

Agency View
An interactive map of the Harris County Flood Control District

Point rainfall data courtesy



www.pbs.org/newshour/hurricane-harvey-became-extreme

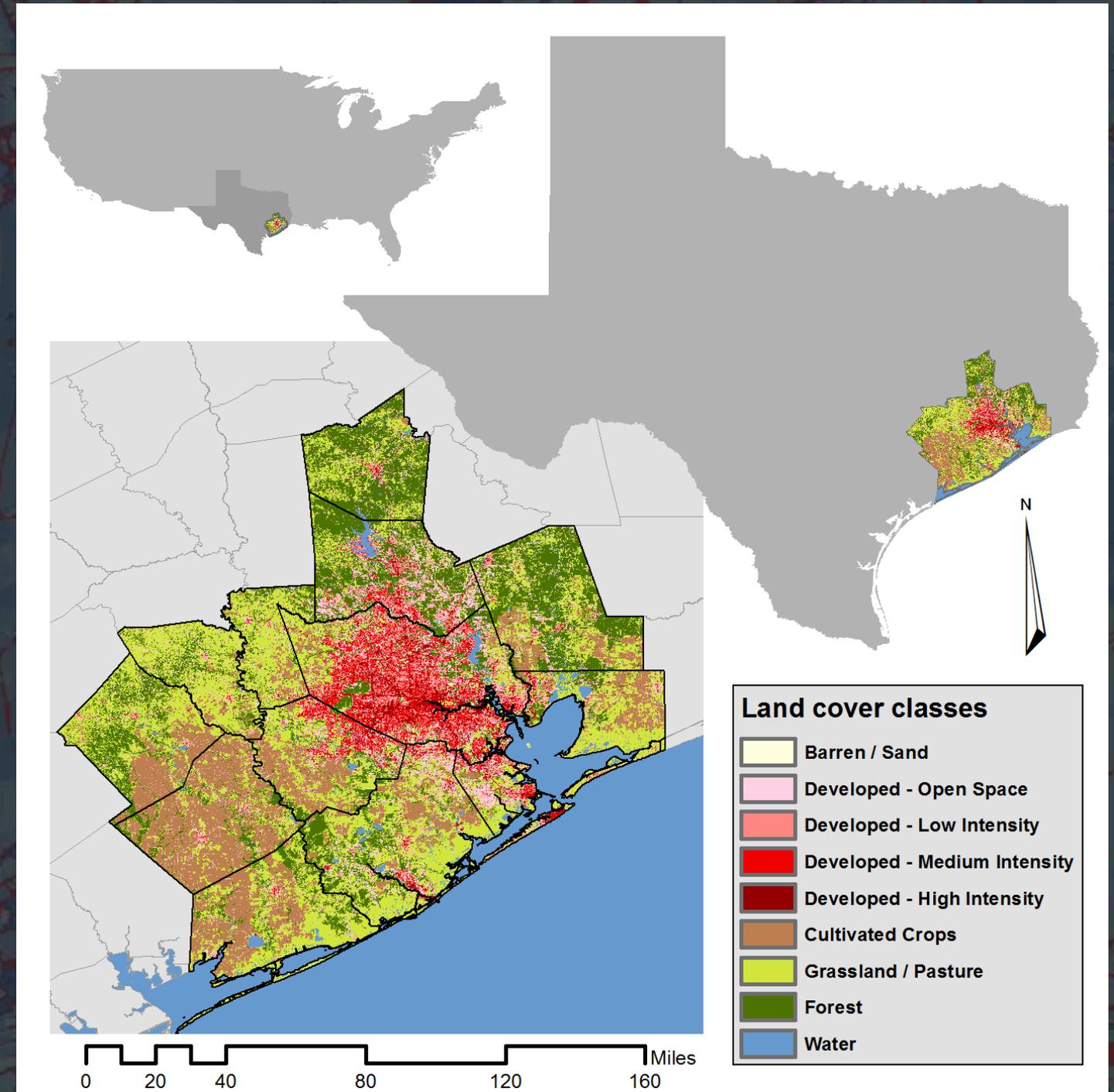


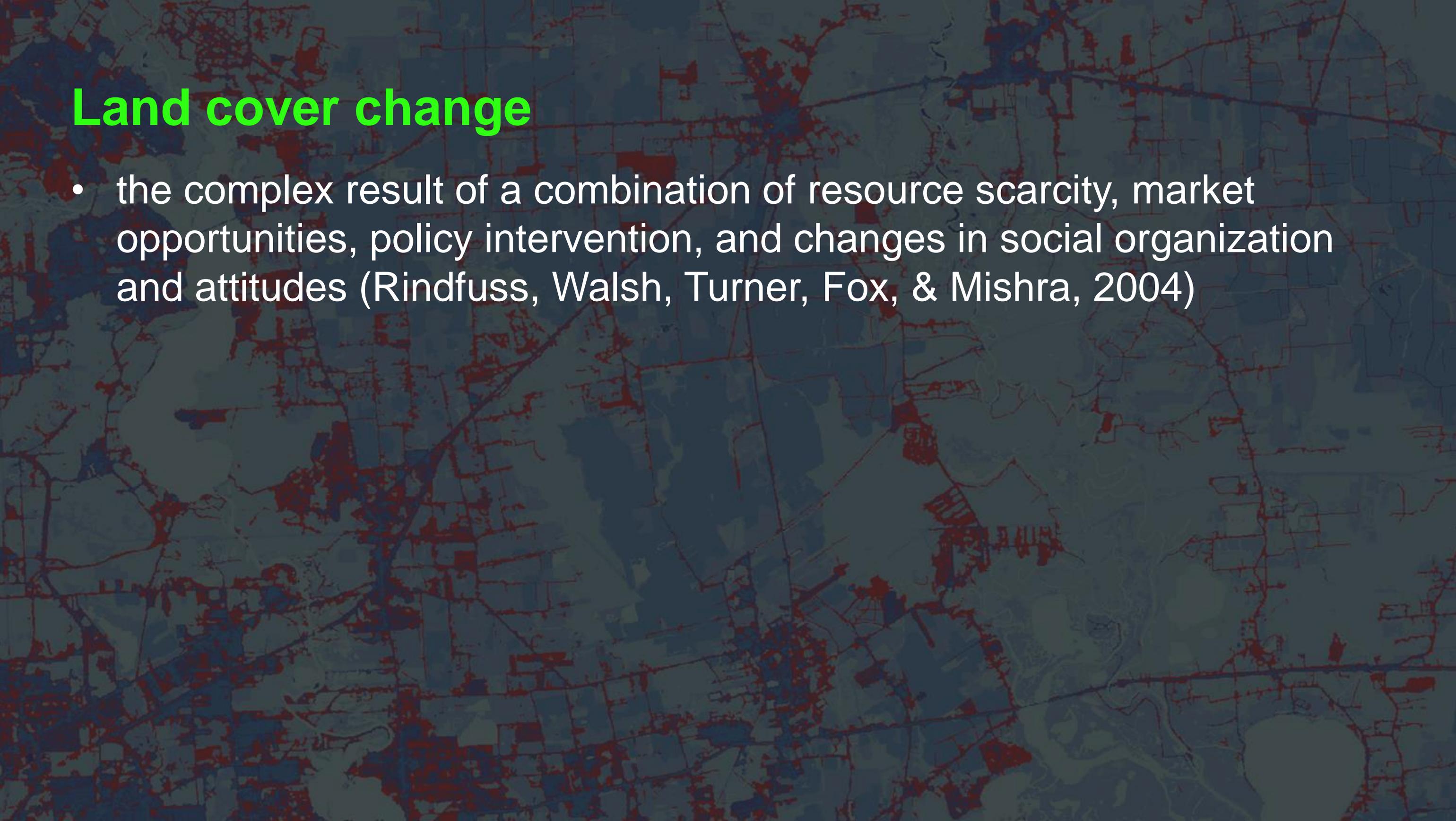
Man-made disaster?

(Joe Raedle/Getty)

“How” is Houston growing?

- where are farms and forests being converted to urban areas?
- where are urban areas growing denser?
- how fast are these changes occurring?





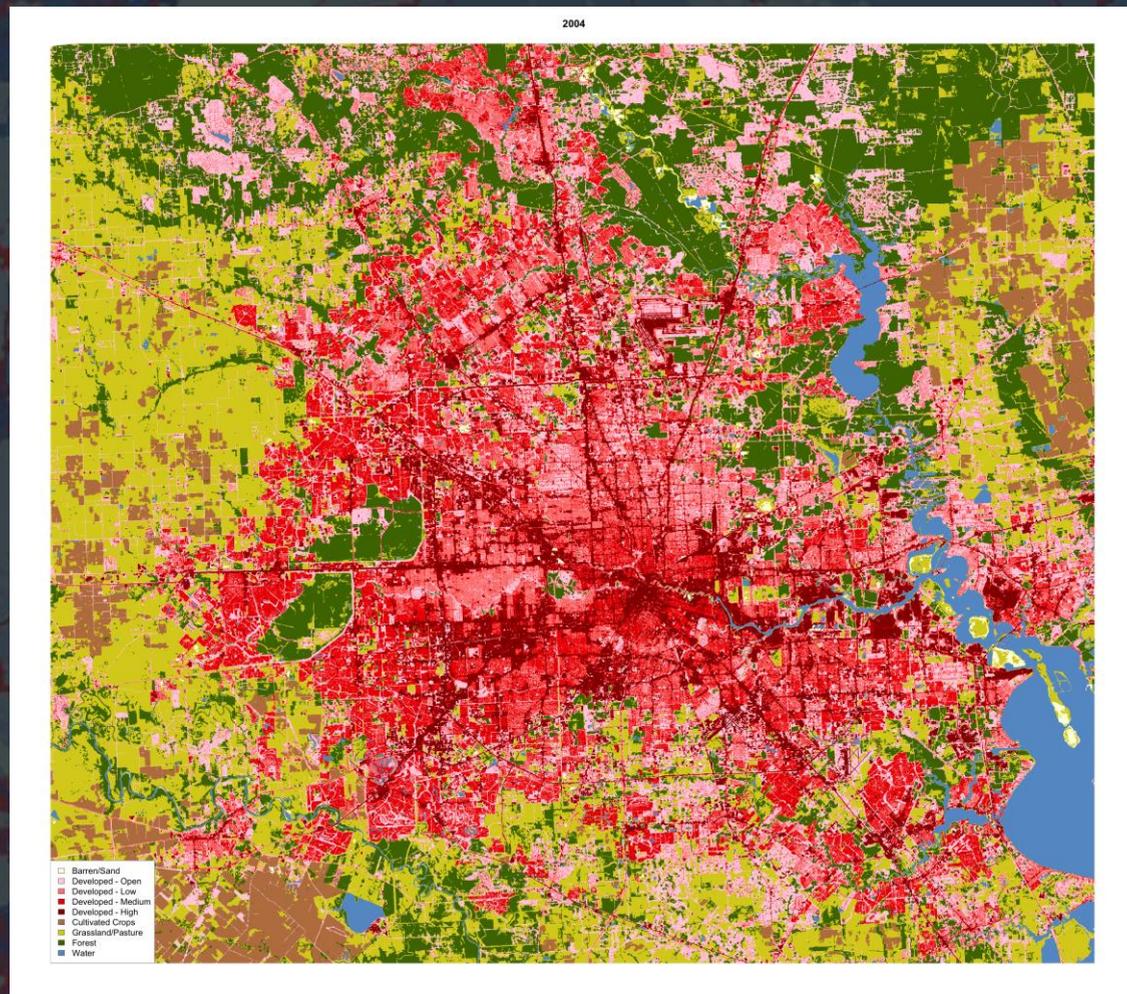
Land cover change

- the complex result of a combination of resource scarcity, market opportunities, policy intervention, and changes in social organization and attitudes (Rindfuss, Walsh, Turner, Fox, & Mishra, 2004)

Urbanization time series: 1997:2018

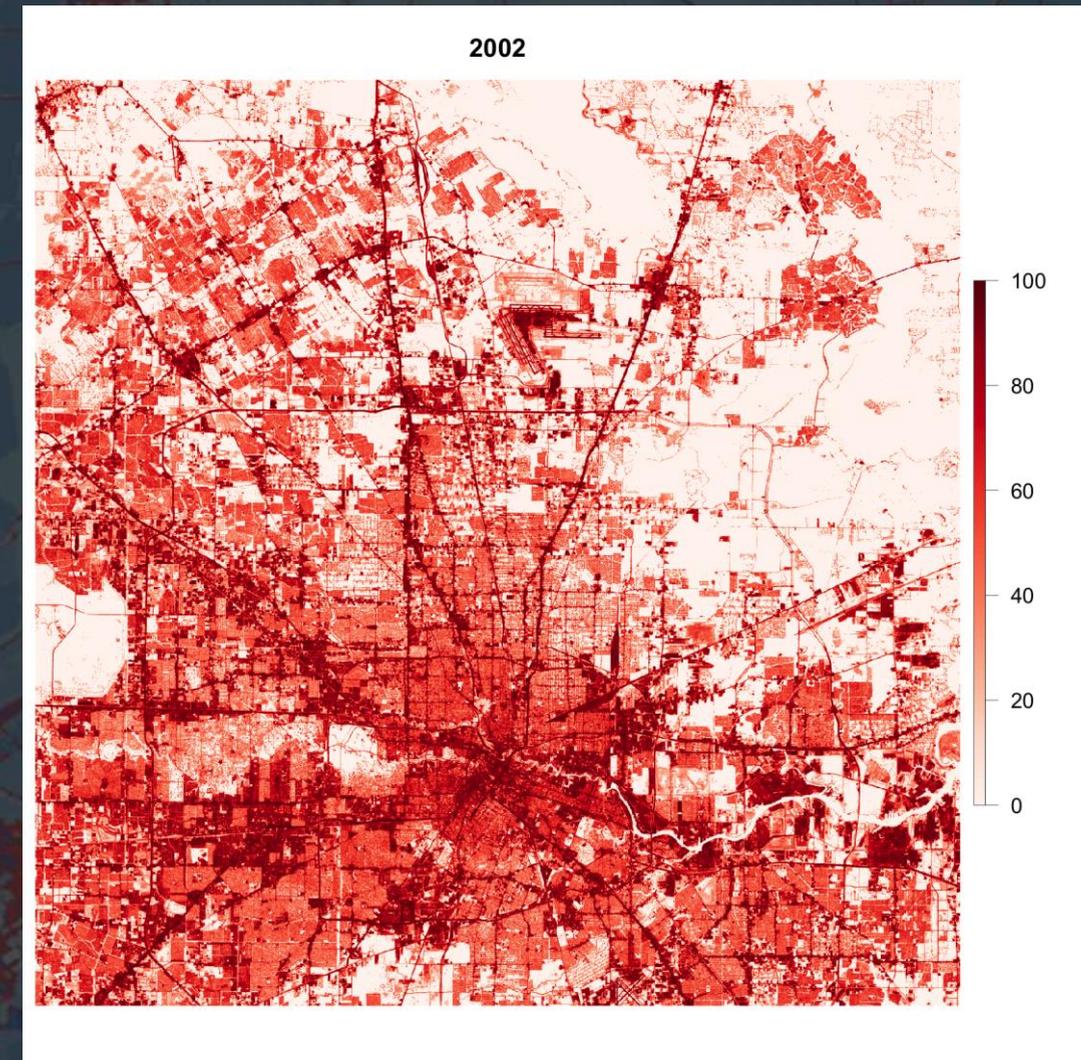
1.

Annual land cover classes



2.

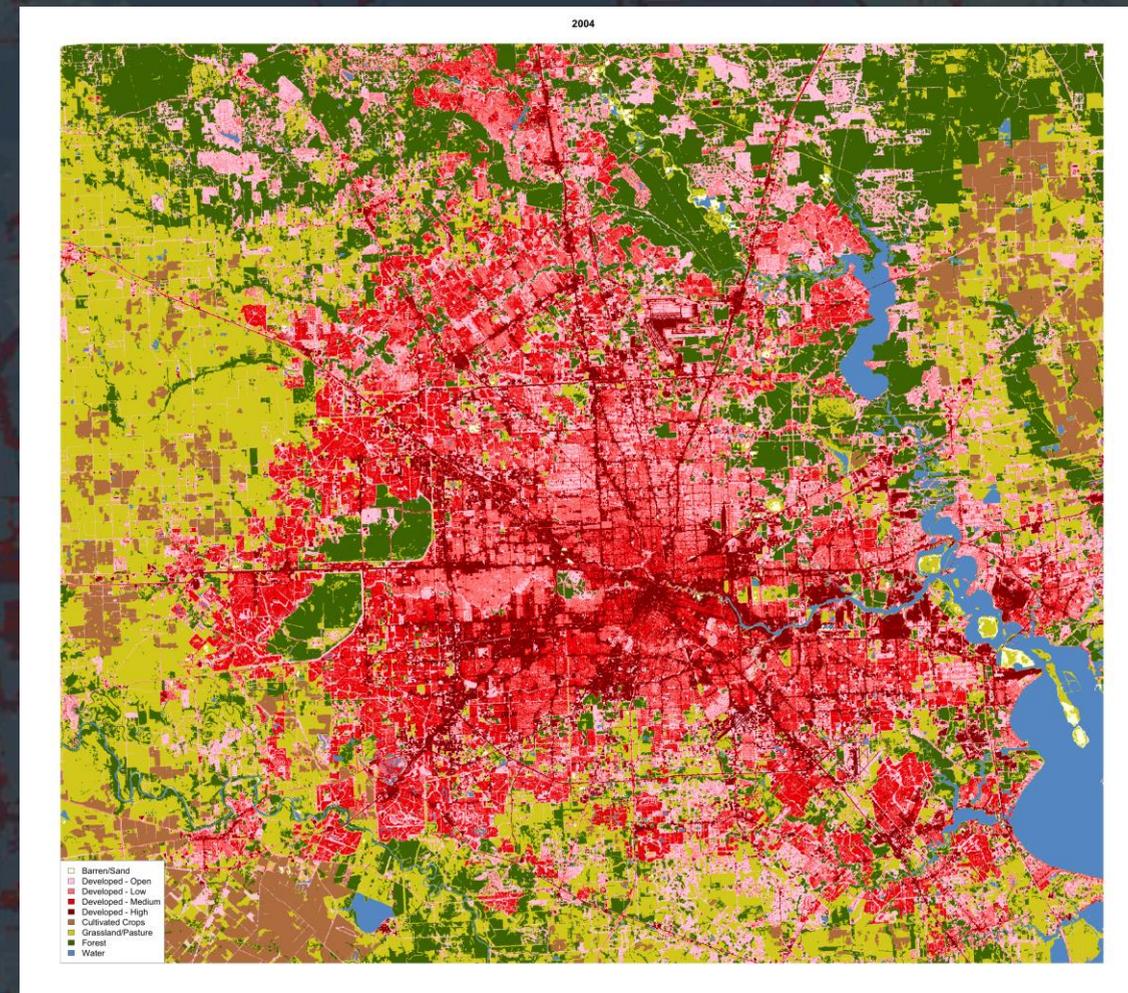
Subannual percent impervious



Urbanization time series: 1997:2018

1.

Annual land cover classes



Annual land cover class change

Temporal extent:

21 years (1997-2017)

Temporal resolution:

Annual

Thematic resolution:

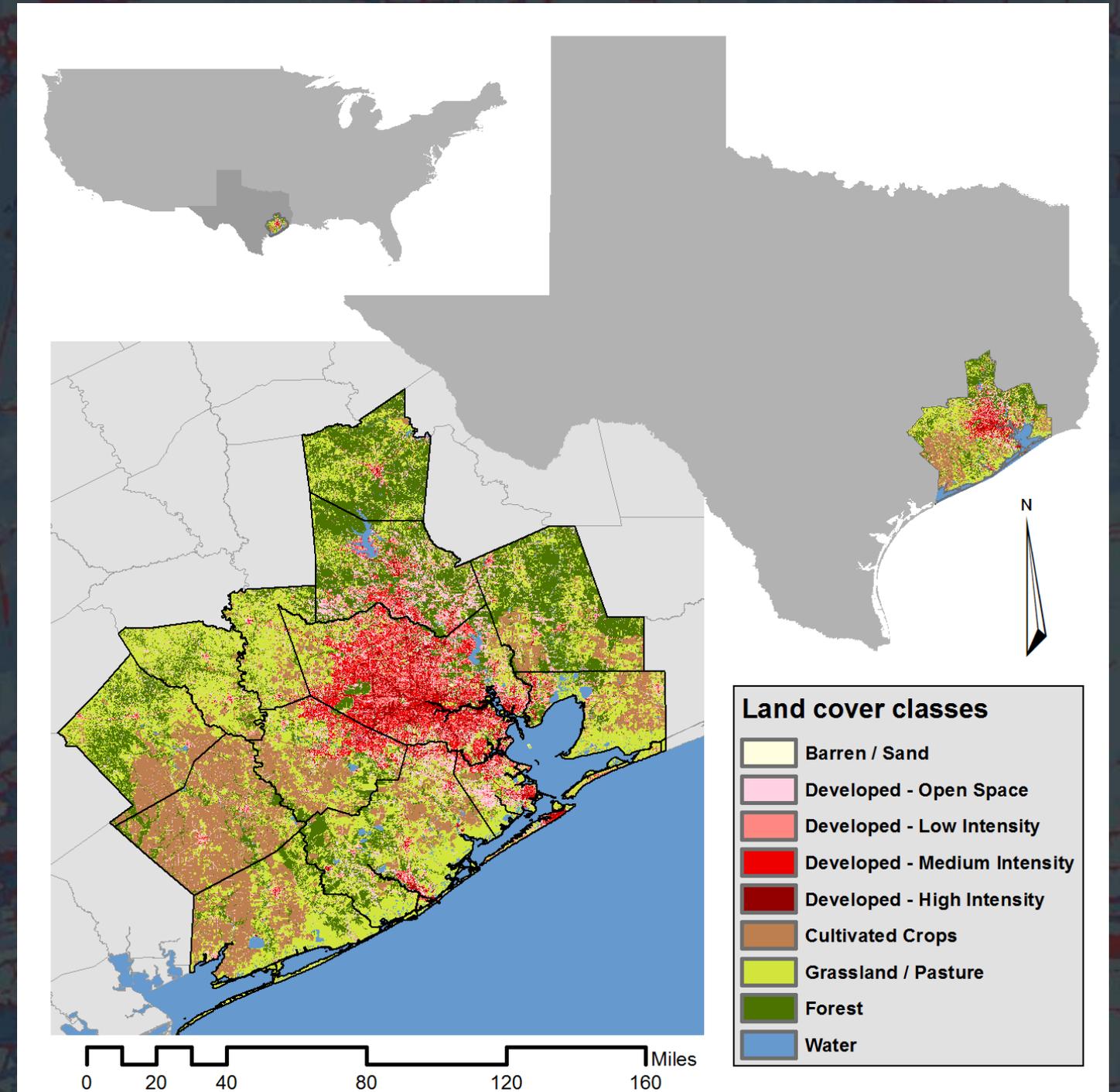
9 classes

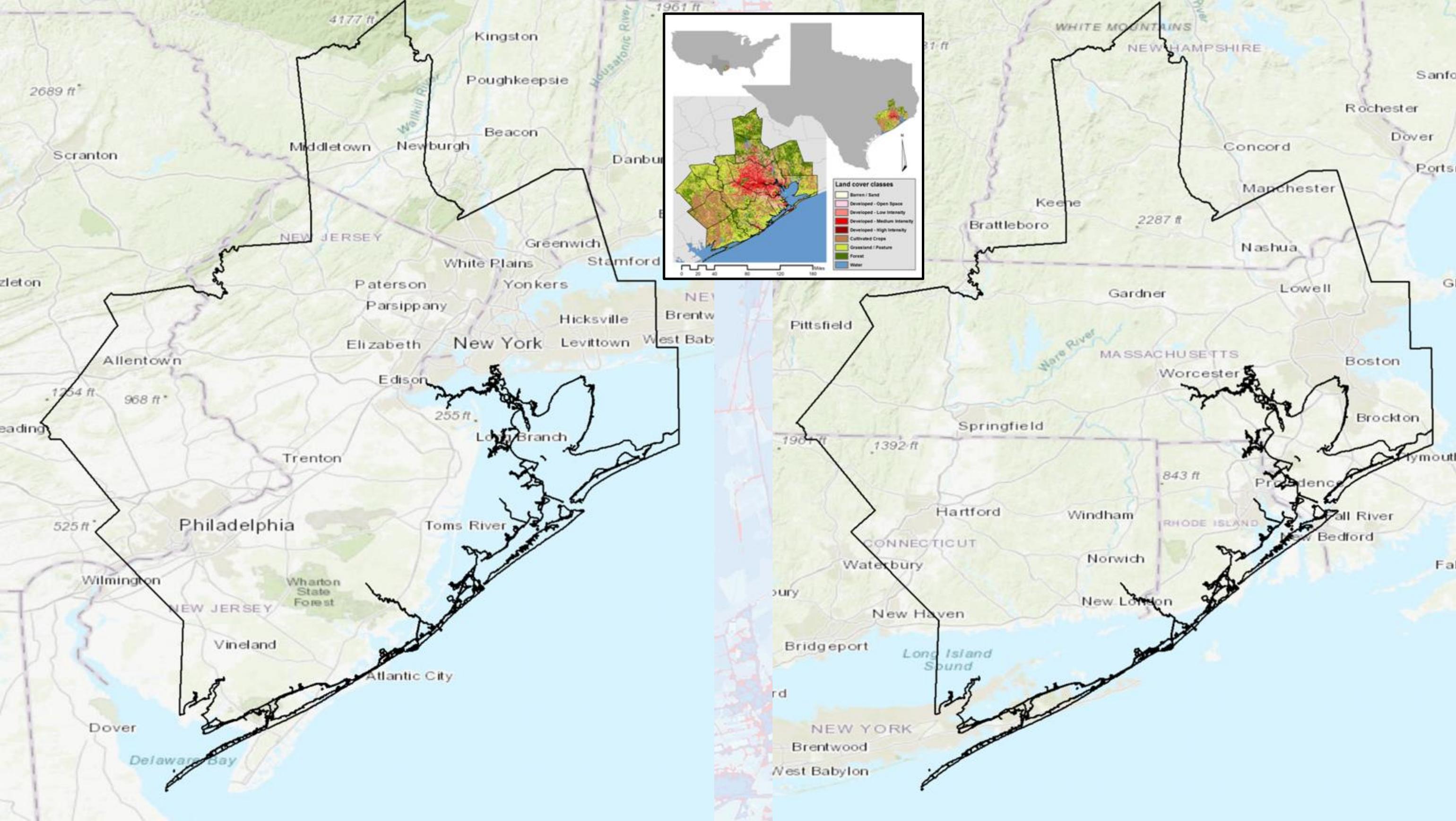
Spatial resolution:

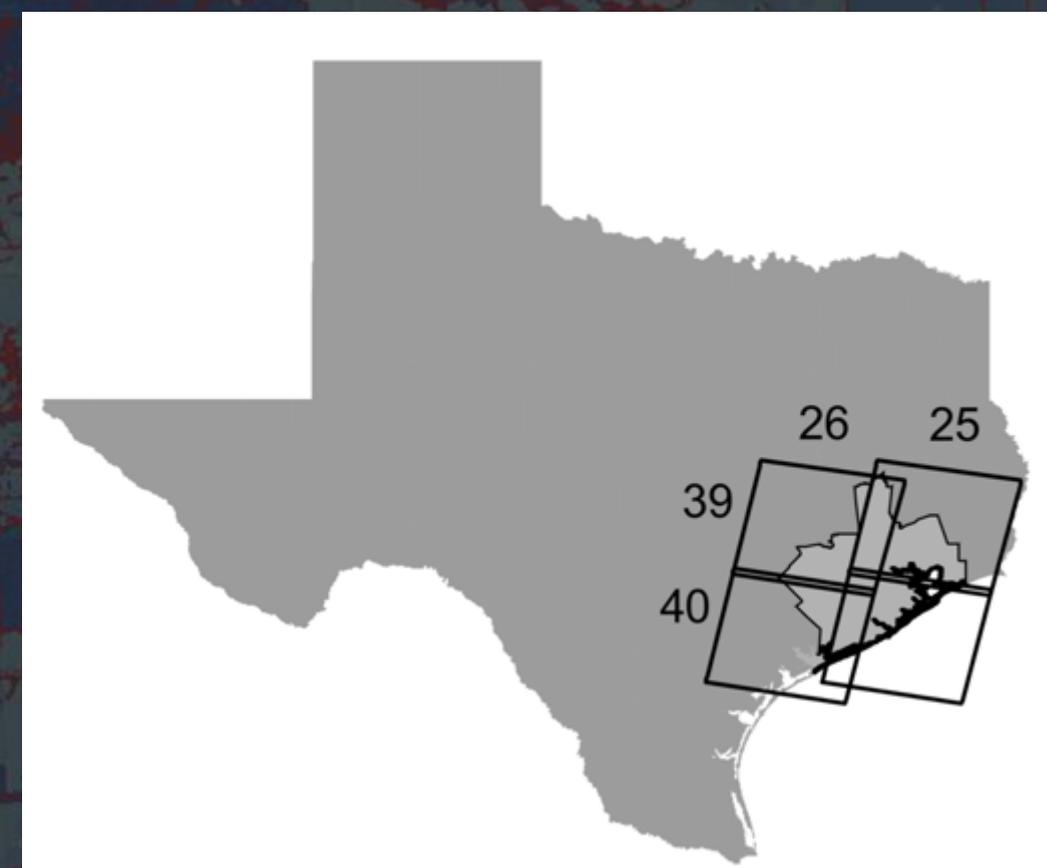
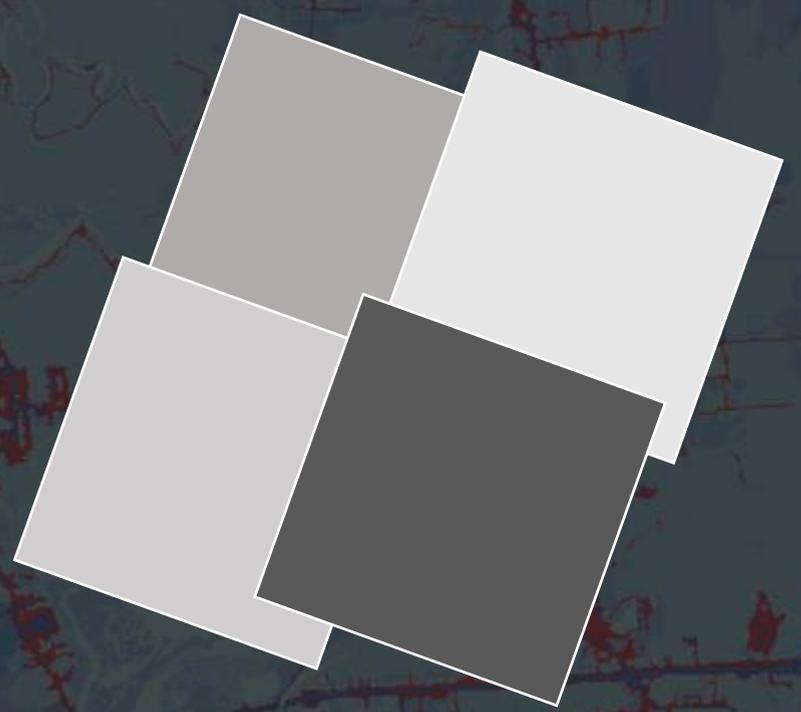
30x30 m

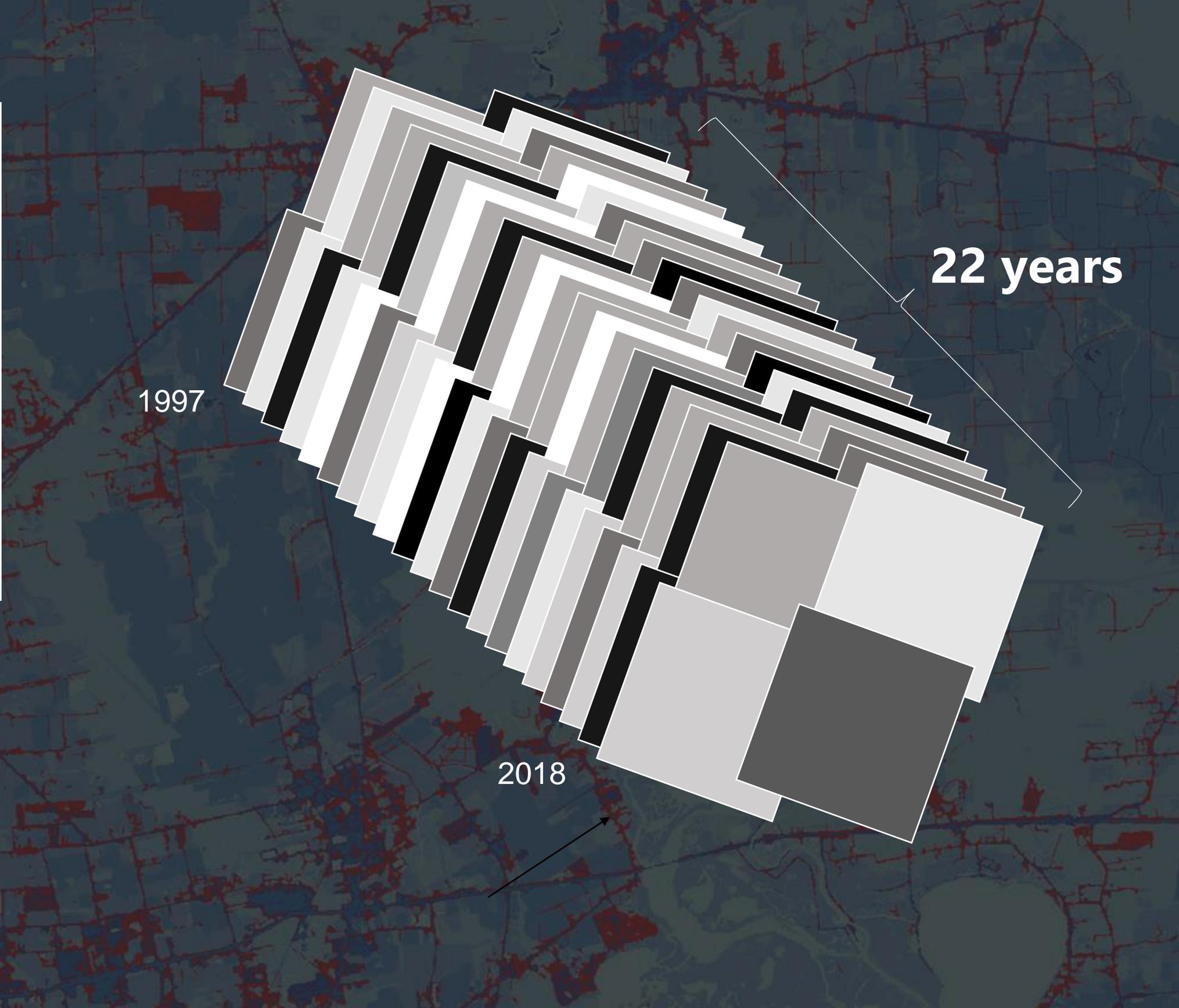
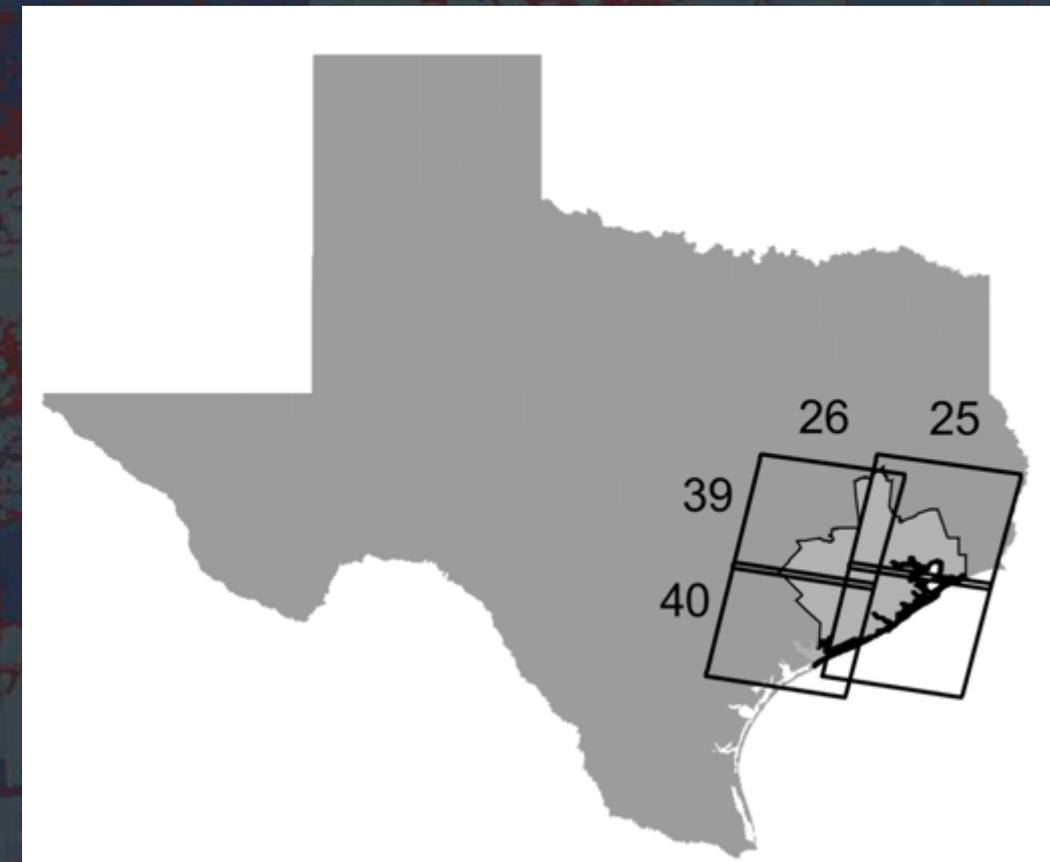
Spatial extent:

35,000 km²









Automatic Adaptive Signature Generalization (AASG)

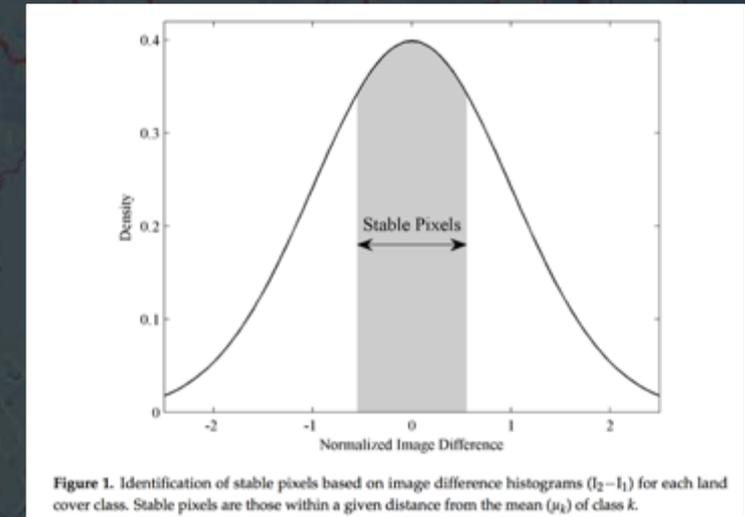
Image (date 1)



Image (date 2)



Image Difference



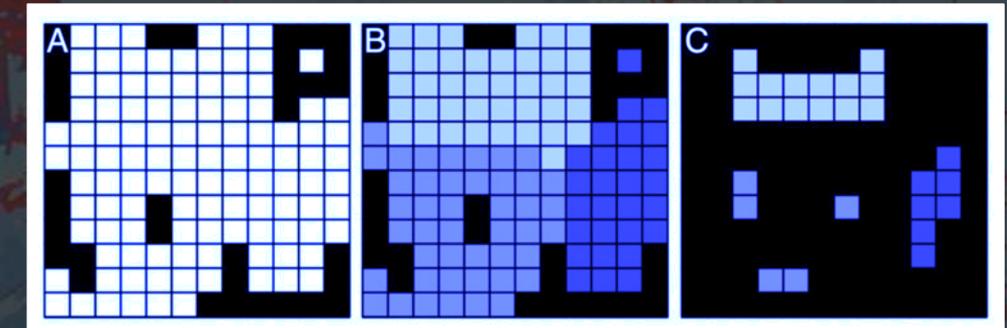
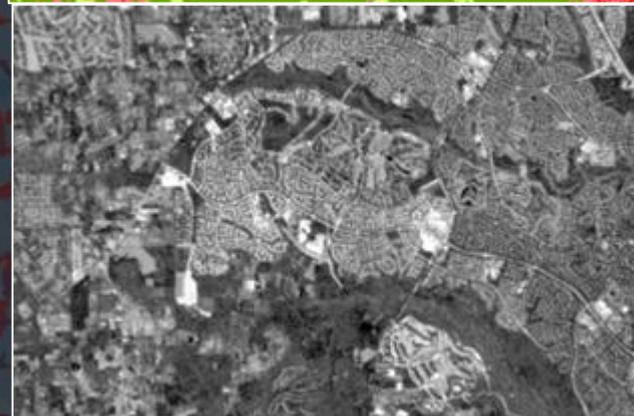
Classification (date 2)



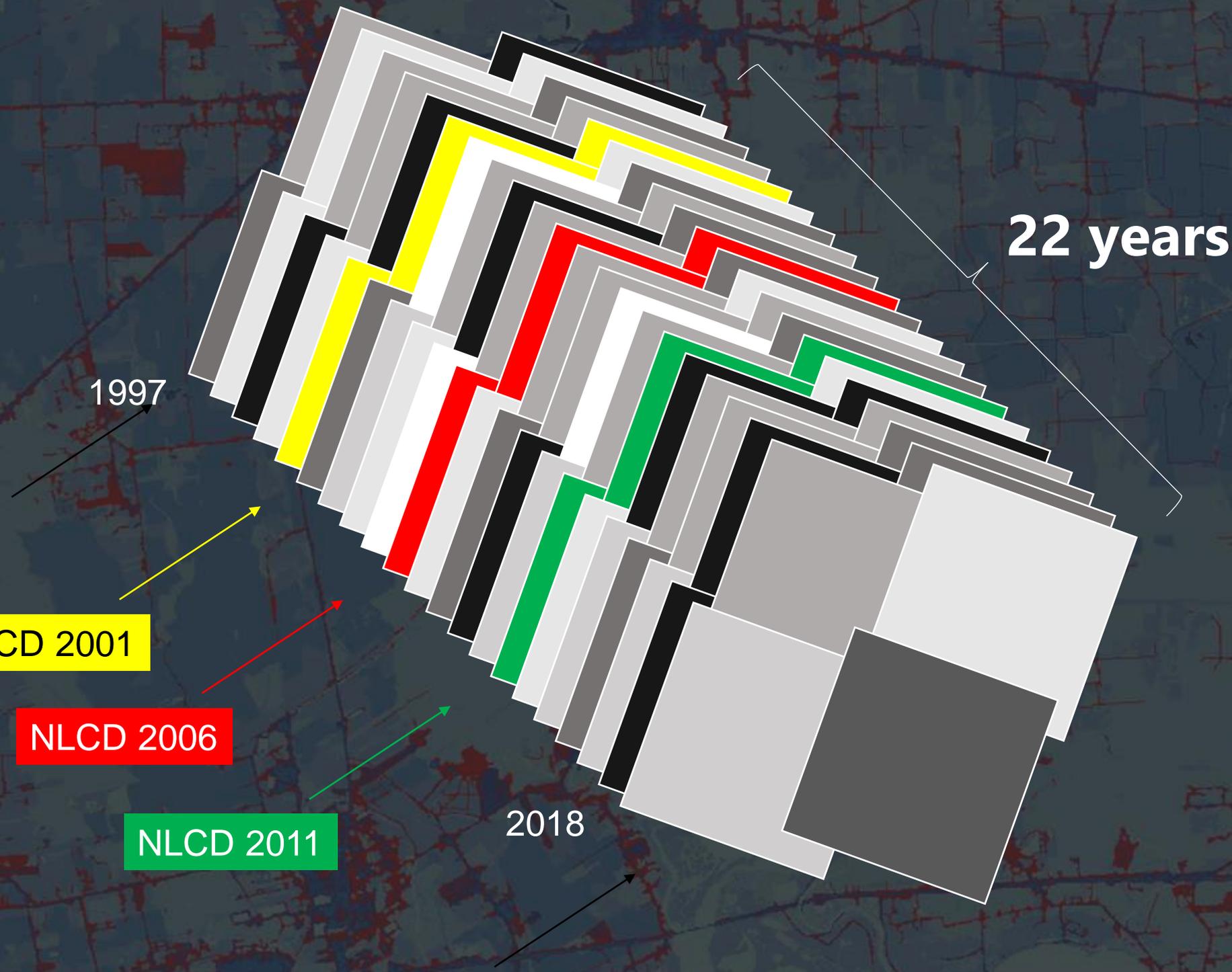
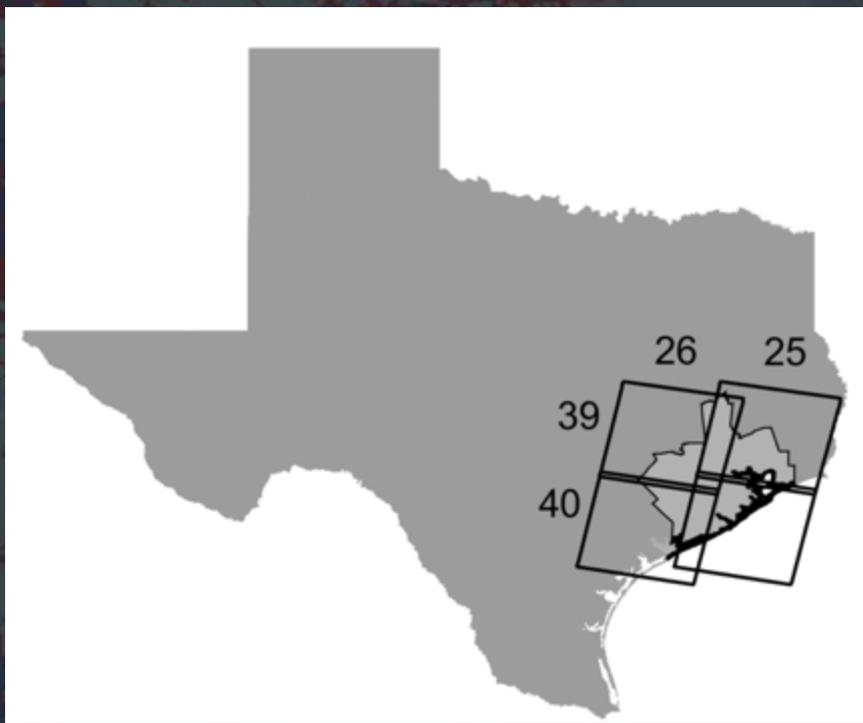
NLCD reference map (date 1)



Image (date 2)



Spatial filters



22 years

1997

NLCD 2001

NLCD 2006

NLCD 2011

2018

The National Land Cover Database

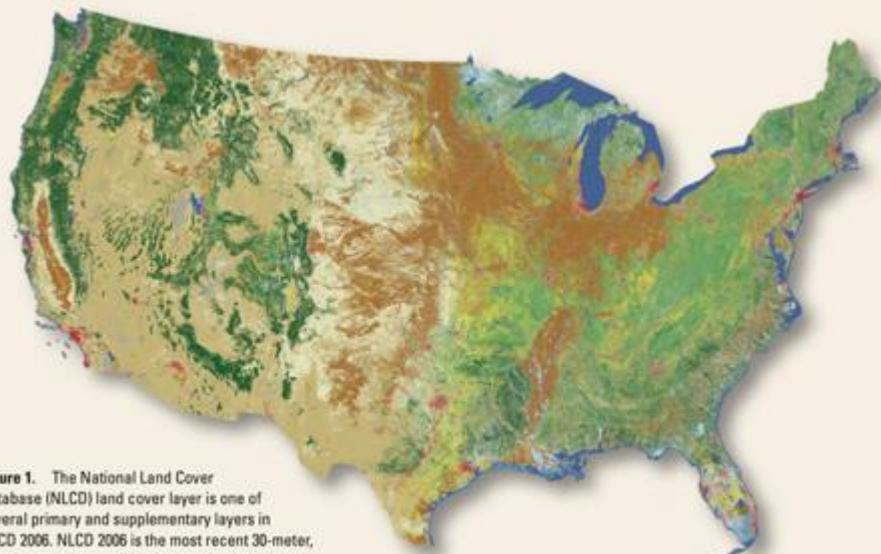


Figure 1. The National Land Cover Database (NLCD) land cover layer is one of several primary and supplementary layers in NLCD 2006. NLCD 2006 is the most recent 30-meter, seamless, wall-to-wall land cover database for the conterminous United States.



Automatic Adaptive Signature Generalization (AASG)

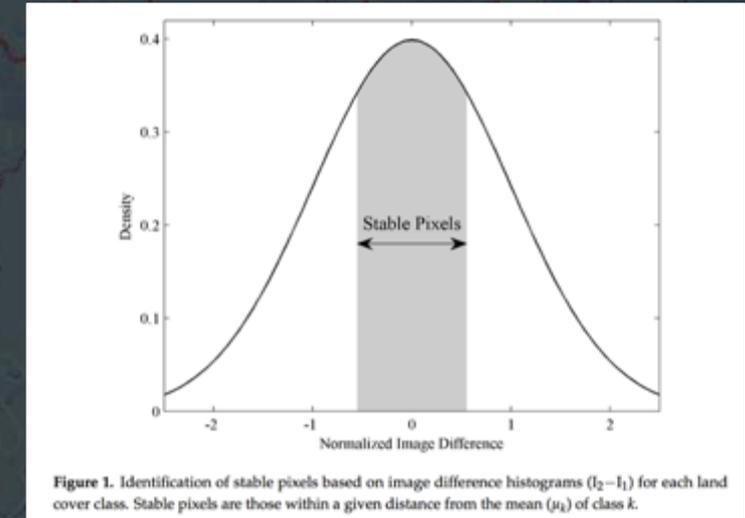
Image (date 1)



Image (date 2)



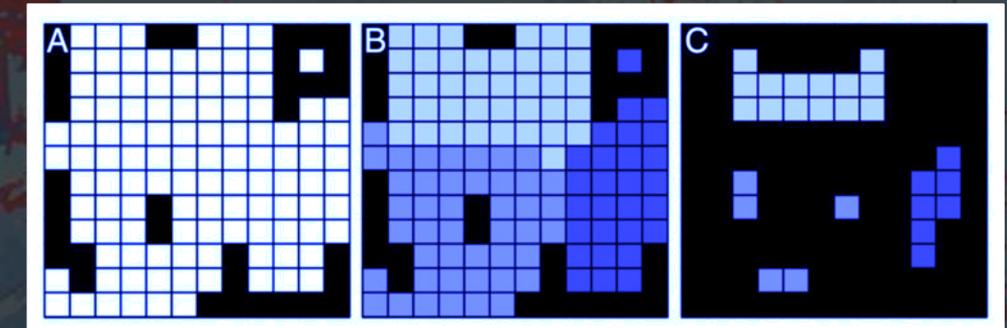
Image Difference



Classification (date 2)

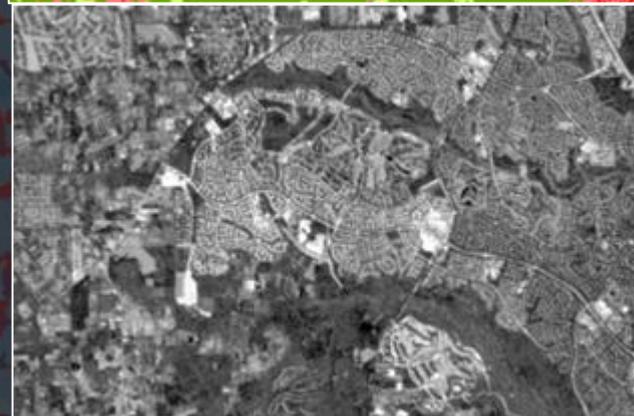


NLCD reference map (date 1)

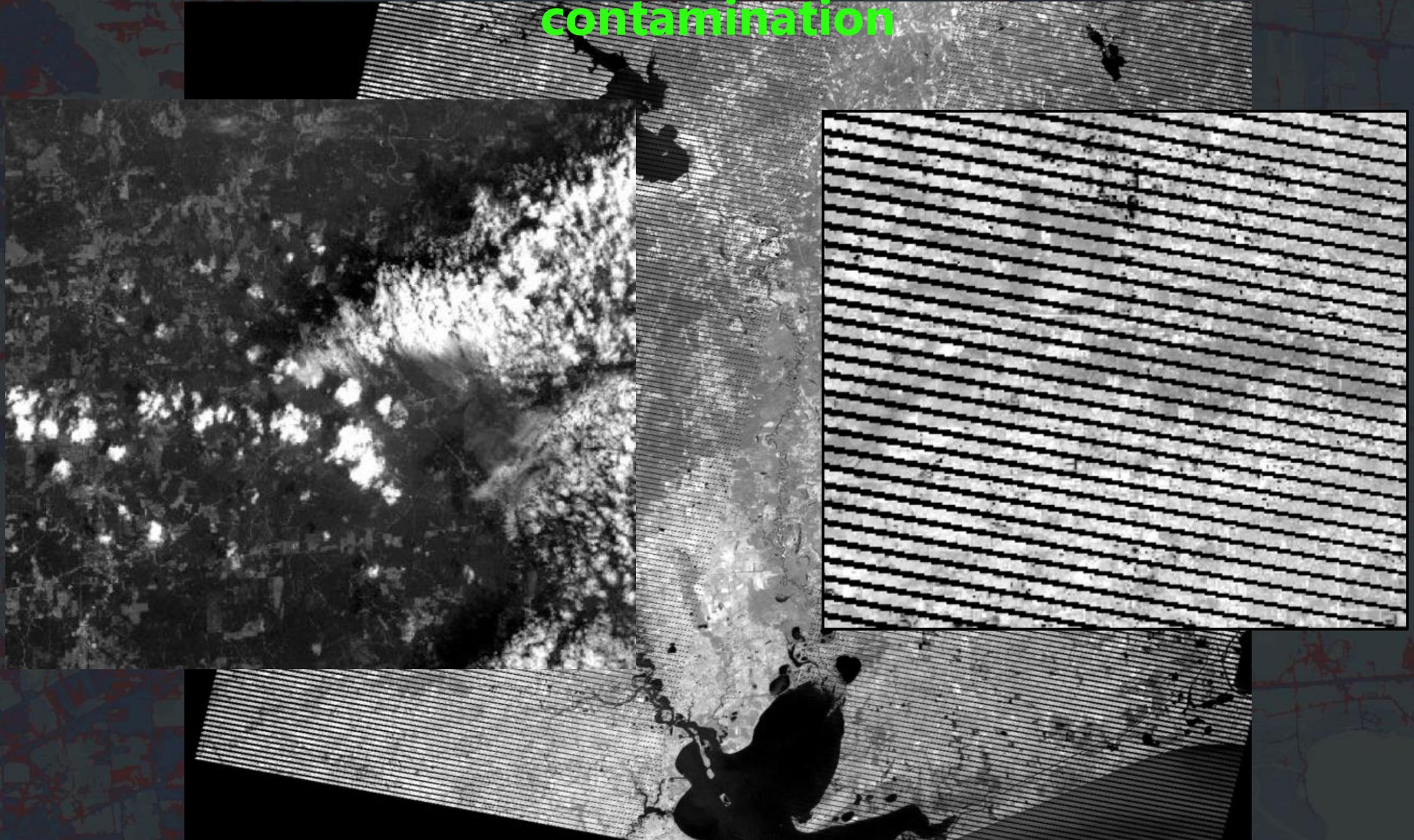


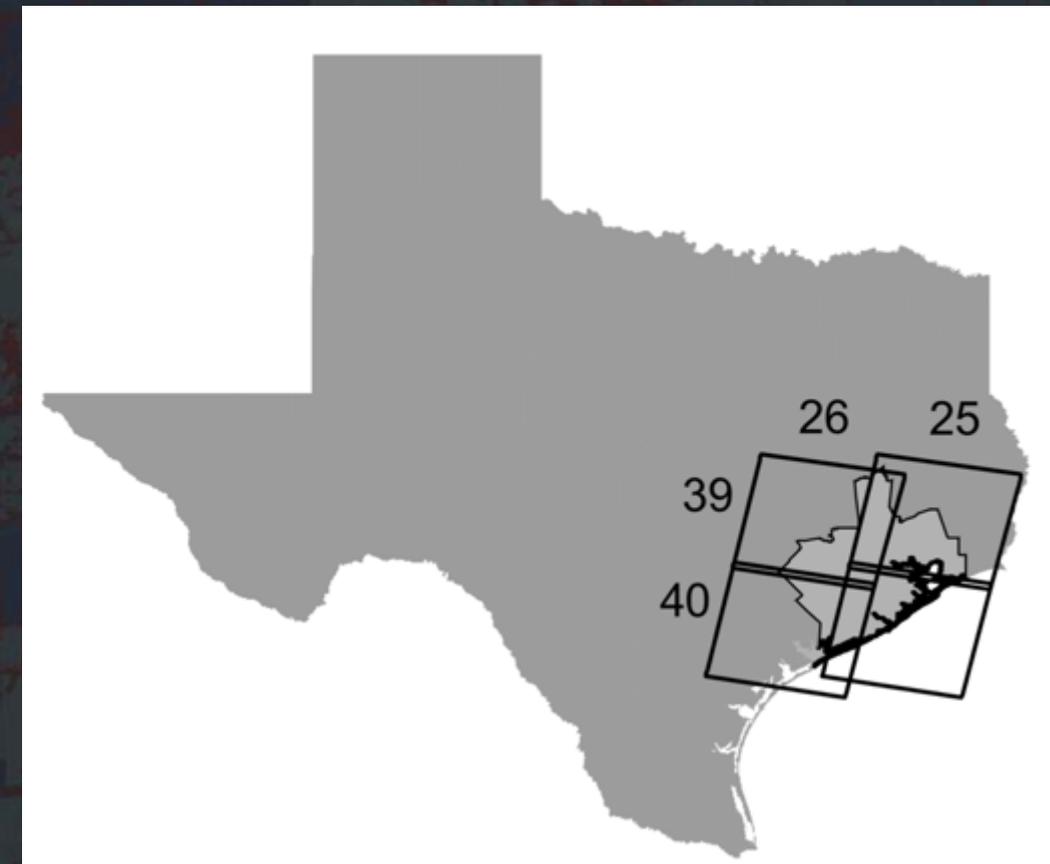
Spatial filters

Image (date 2)



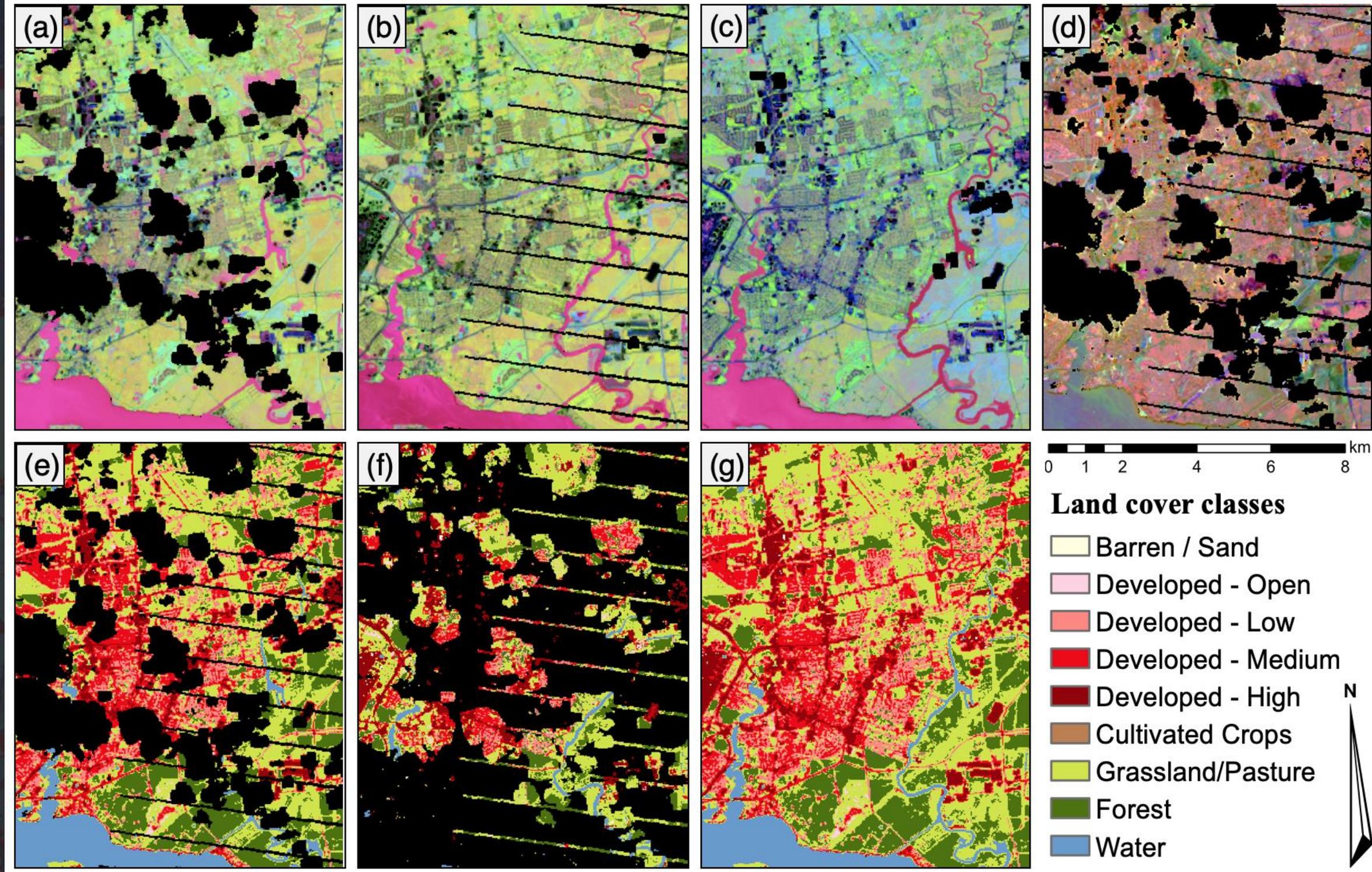
Clouds, error, and contamination



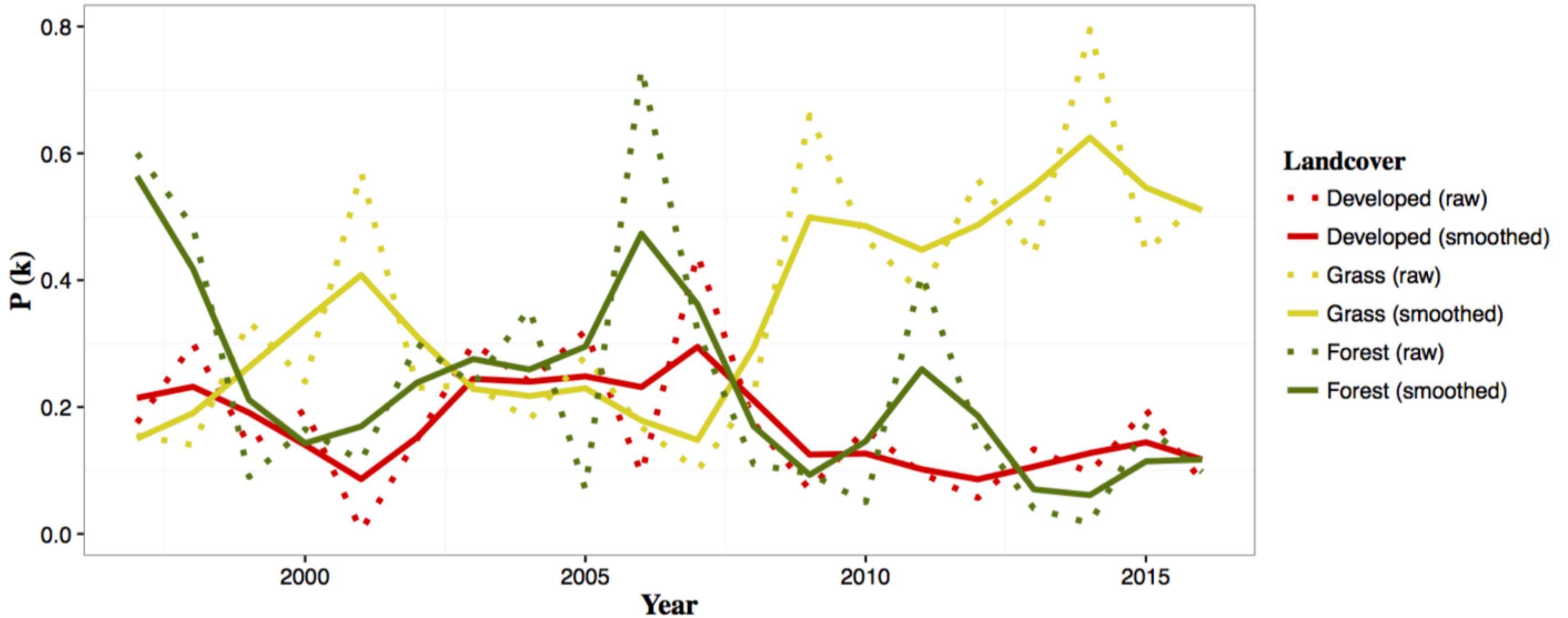


3-7 images per year

Clouds, error, and contamination



Spatio-temporal filtering



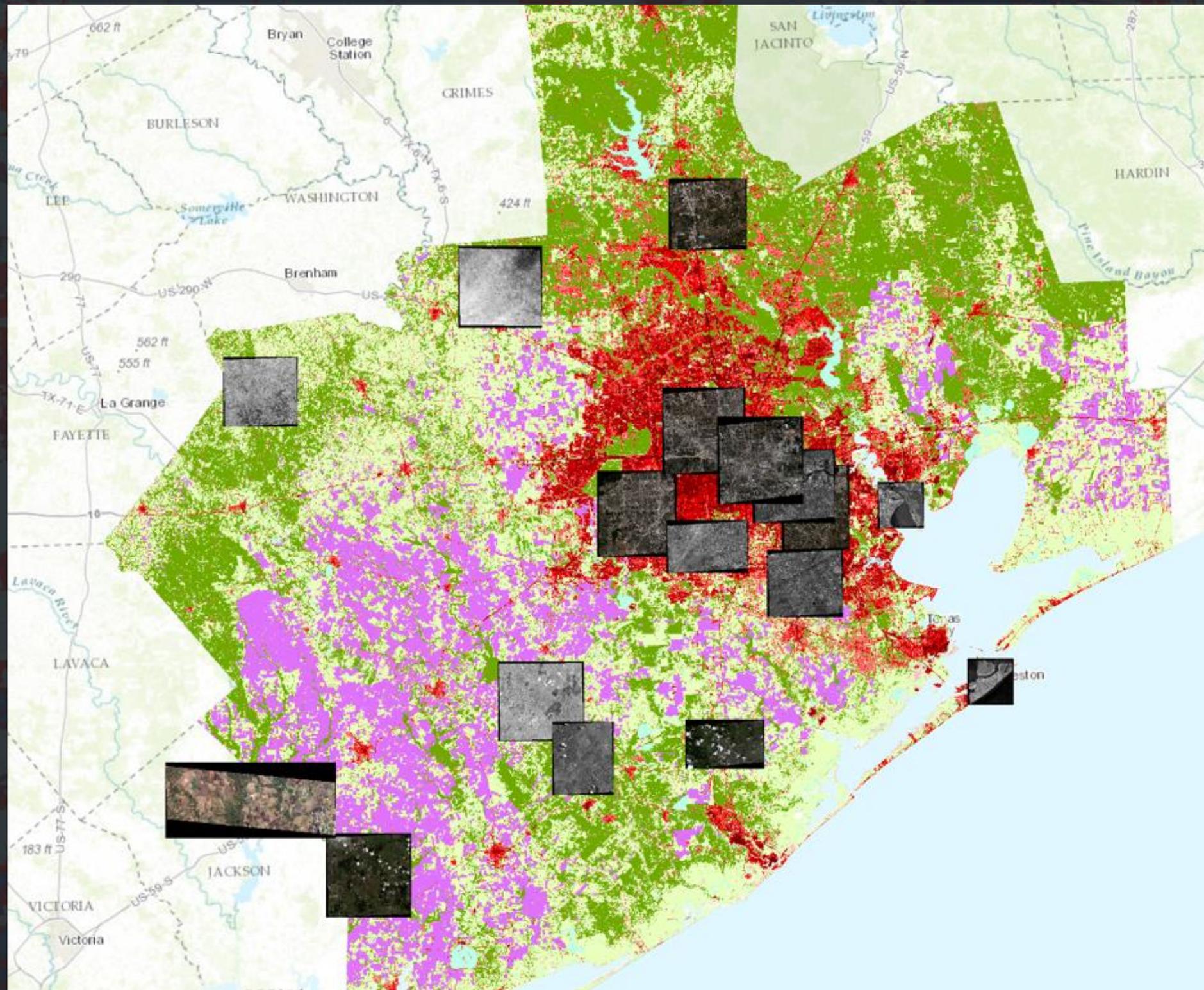
Accuracy Assessment

NLCD agreement

Table 2. Agreement with NLCD maps for 2001, 2006, and 2011 (%). U_{AG} – user's agreement; P_{AG} – producer's agreement; O_{AG} – overall agreement. NLCD as reference.

	2001		2006		2011	
	U_{AG} (%)	P_{AG} (%)	U_{AG} (%)	P_{AG} (%)	U_{AG} (%)	P_{AG} (%)
Barren/Sand	71.0	30.5	63.9	28.9	67.6	29.6
Developed-Open	58.1	76.9	53.9	74.9	52.0	74.4
Developed-Low	48.1	43.6	44.0	48.0	43.2	49.4
Developed-Medium	60.7	45.6	57.3	51.4	60.0	50.7
Developed-High	58.0	71.0	54.7	73.7	56.4	73.1
Cultivated Crops	80.0	76.7	80.1	76.3	80.1	76.2
Grassland/Pasture	75.3	81.5	75.8	79.9	76.1	78.9
Forest	86.8	76.9	88.2	75.1	87.1	75.2
Water	84.4	99.5	84.9	99.4	85.7	97.7
O_{AG}	75.7		74.9		74.3	

Accuracy Assessment



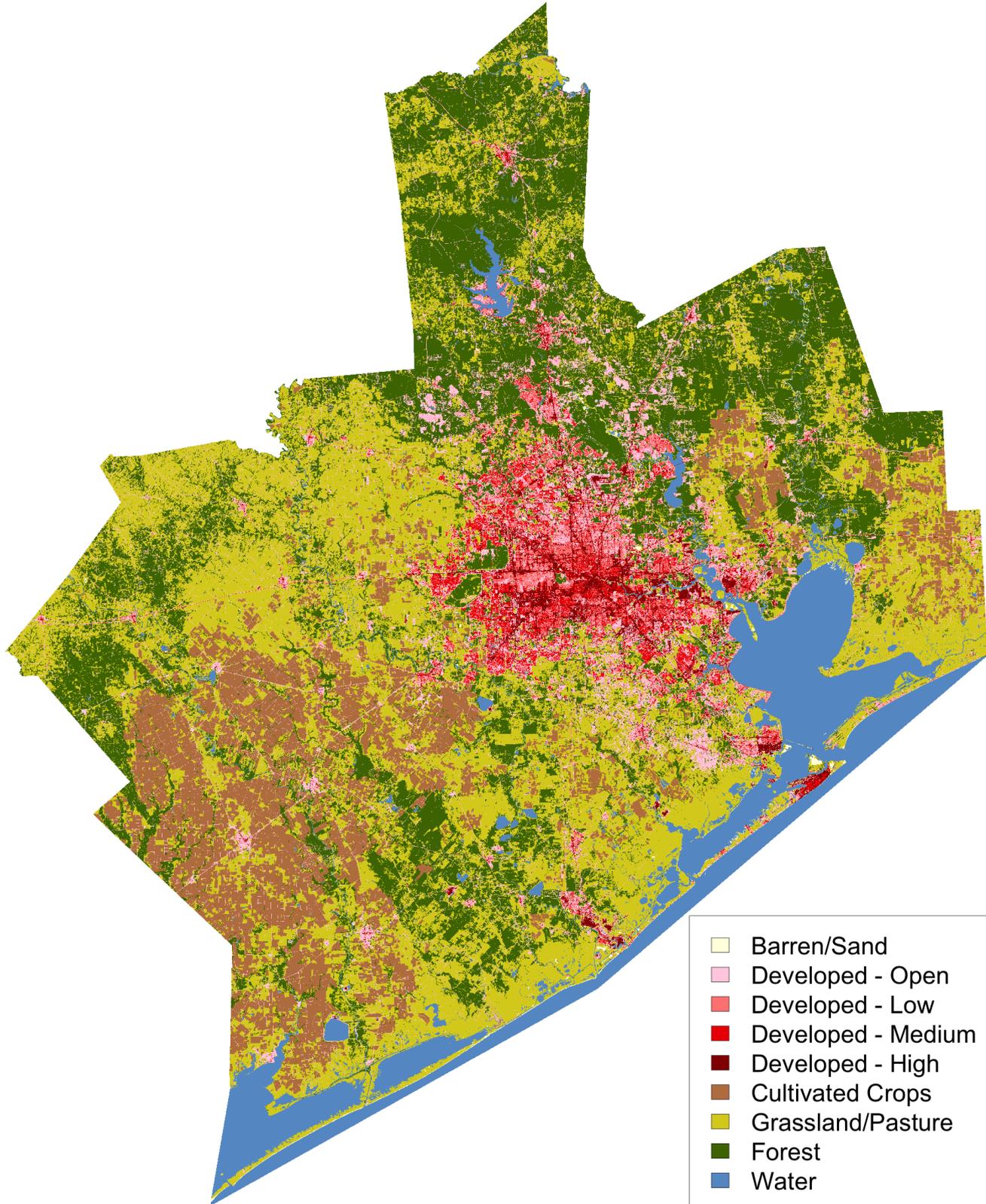
Accuracy Assessment

Fuzzy accuracy (multi-temporal independent validation)

Table 5. Fuzzy accuracy assessment. *UA* – user’s accuracy; *OA* – overall accuracy, followed by 95% confidence intervals. Fuzzy linguistic scale following Woodcock and Gopal (2000): good answer (‘Good’) and reasonable or acceptable (‘Acceptable’).

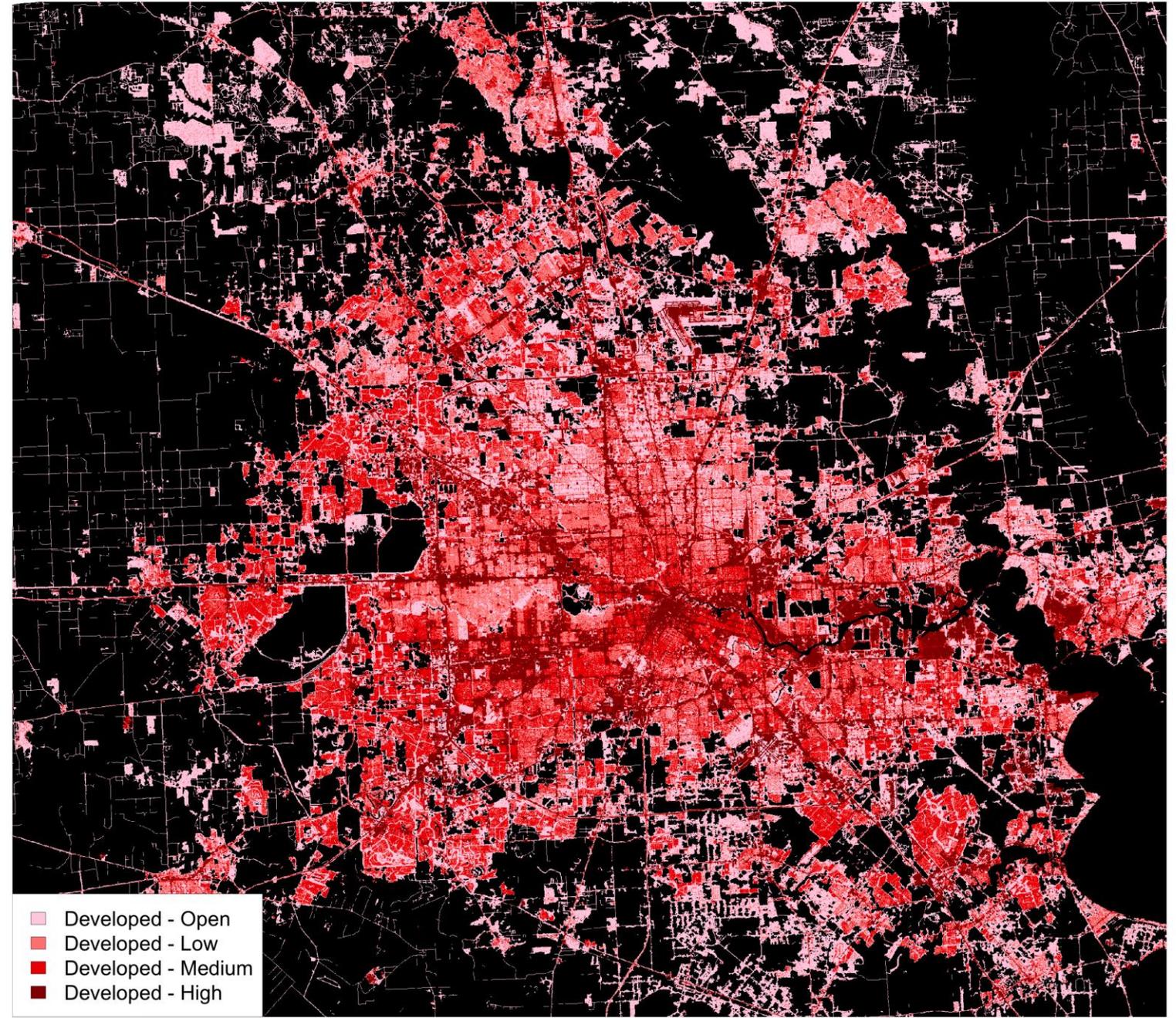
		Reference	
		<i>UA</i> ‘Good’ (%)	<i>UA</i> ‘Acceptable’ (%)
Map	Barren/Sand	96.3 ± 4.2	97.5 ± 3.4
	Developed-Open	71.8 ± 5.6	86.5 ± 4.4
	Developed-Low	83.0 ± 3.8	97.2 ± 1.7
	Developed-Med	83.8 ± 3.8	95.3 ± 2.1
	Developed-High	92.5 ± 2.9	96.2 ± 2.0
	Cultivated Crops	85.9 ± 5.5	87.8 ± 5.1
	Grassland/Pasture	95.1 ± 1.6	96.4 ± 1.3
	Forest	93.0 ± 2.2	95.2 ± 1.8
	Water	95.8 ± 2.7	95.8 ± 2.7
	<i>OA</i>	90.6 ± 1.1	94.2 ± 1.0

1997

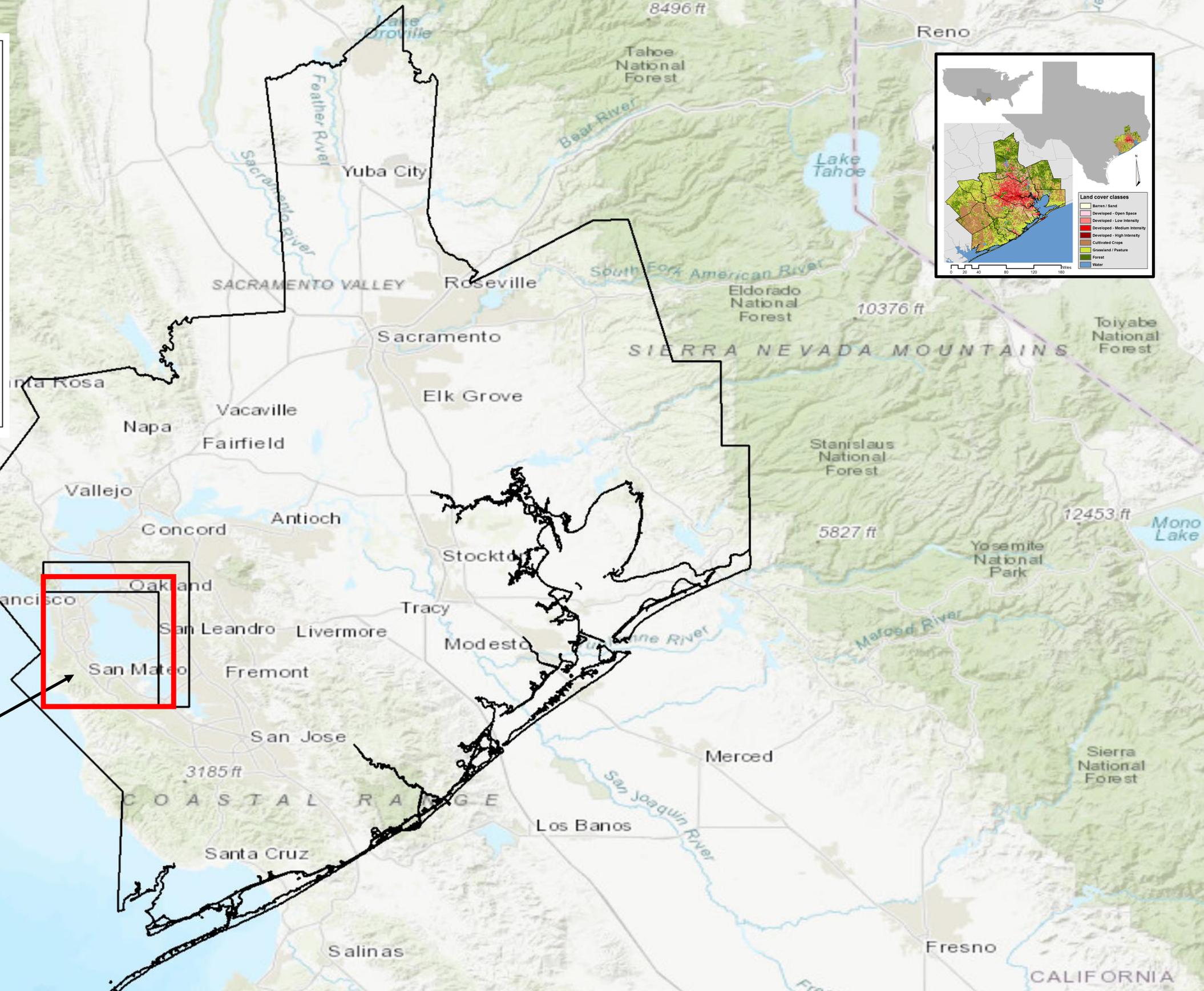
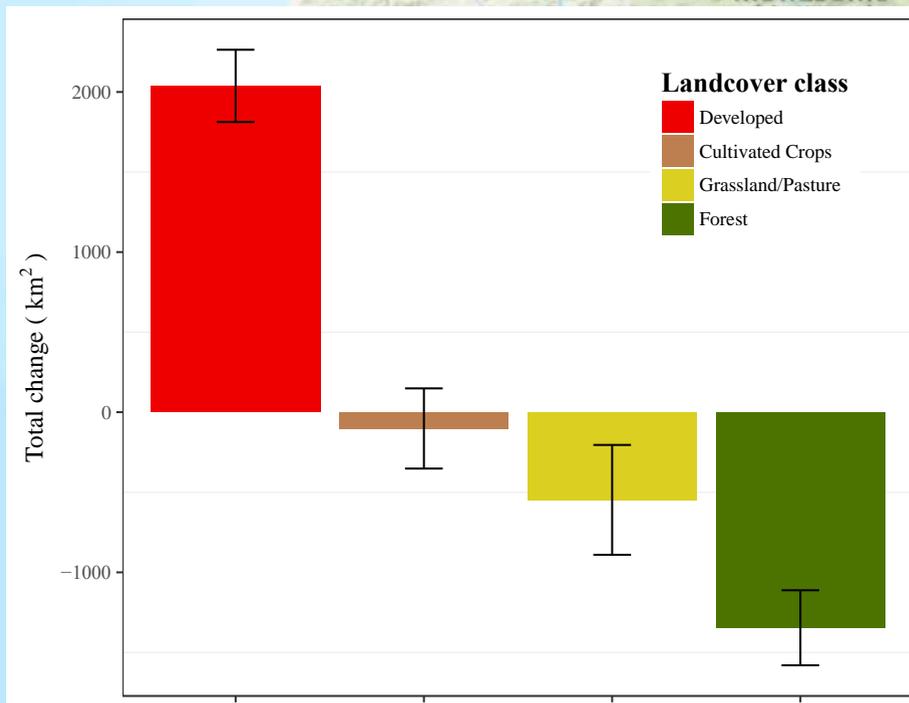


- Barren/Sand
- Developed - Open
- Developed - Low
- Developed - Medium
- Developed - High
- Cultivated Crops
- Grassland/Pasture
- Forest
- Water

1997



- Developed - Open
- Developed - Low
- Developed - Medium
- Developed - High



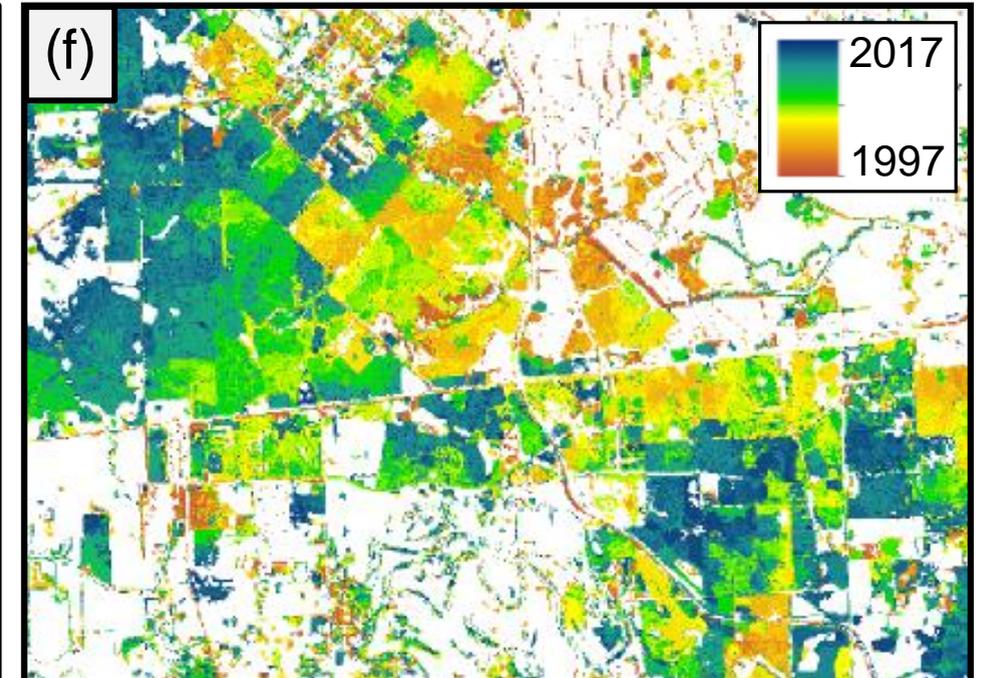
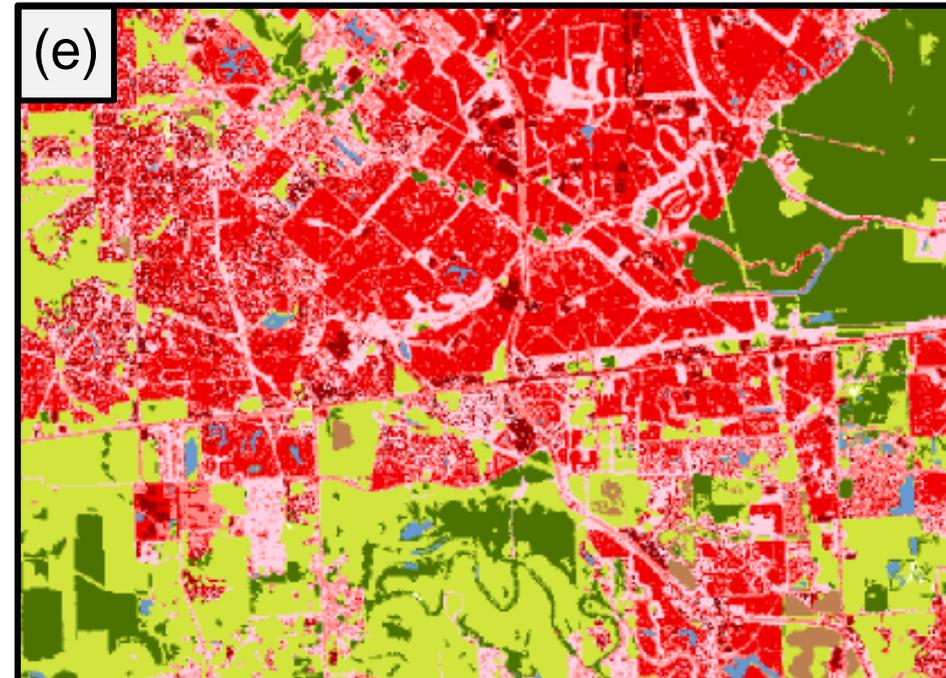
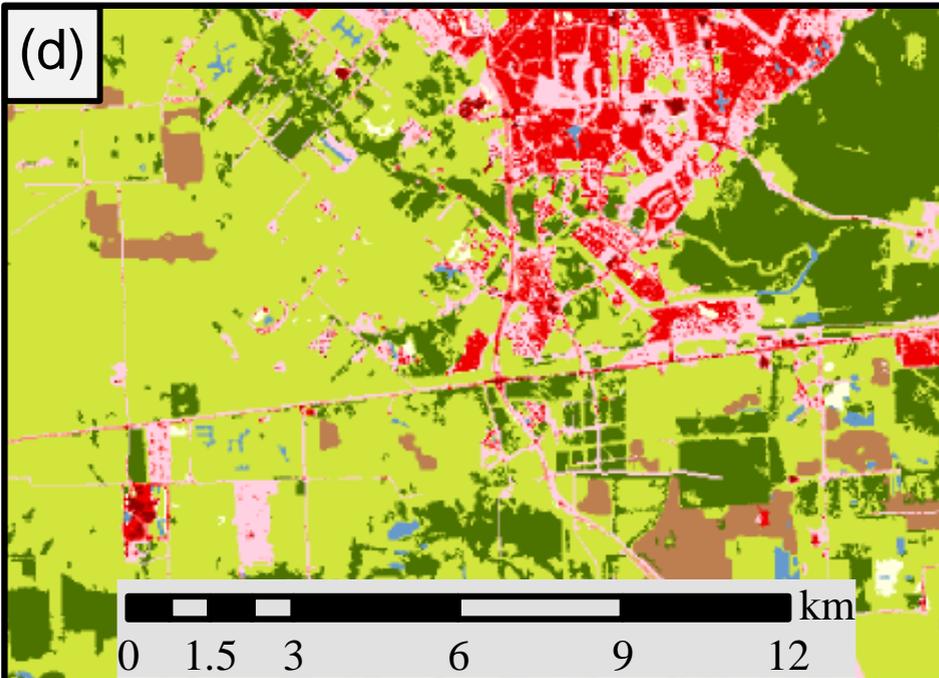
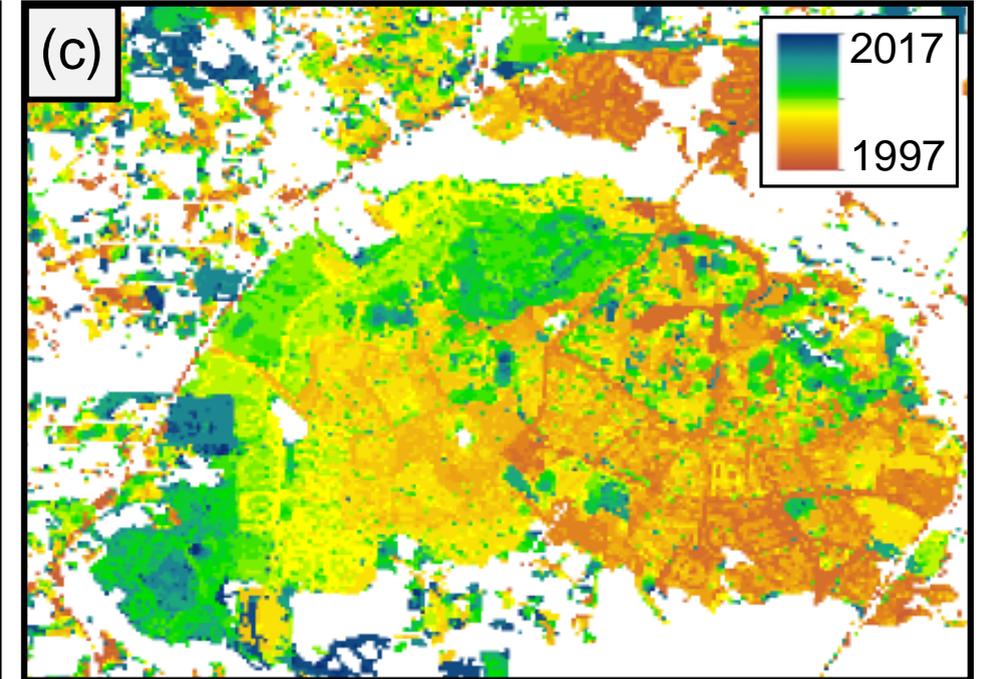
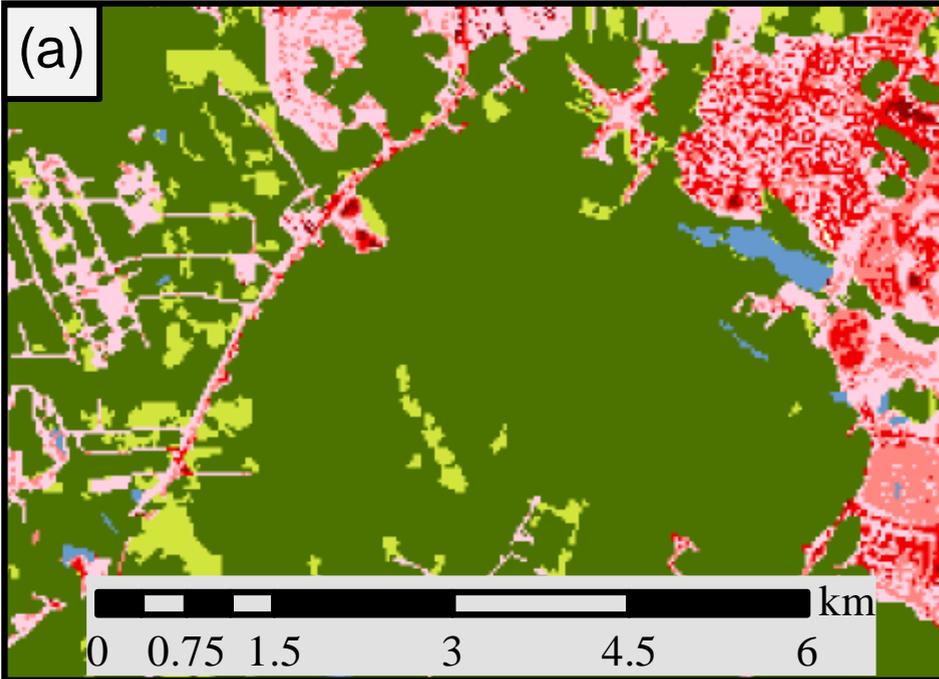
Equivalent area developed in Houston from 1997 to 2017 (2040km² ± 400km²)

Year of conversion (The Woodlands & Cinco Ranch)

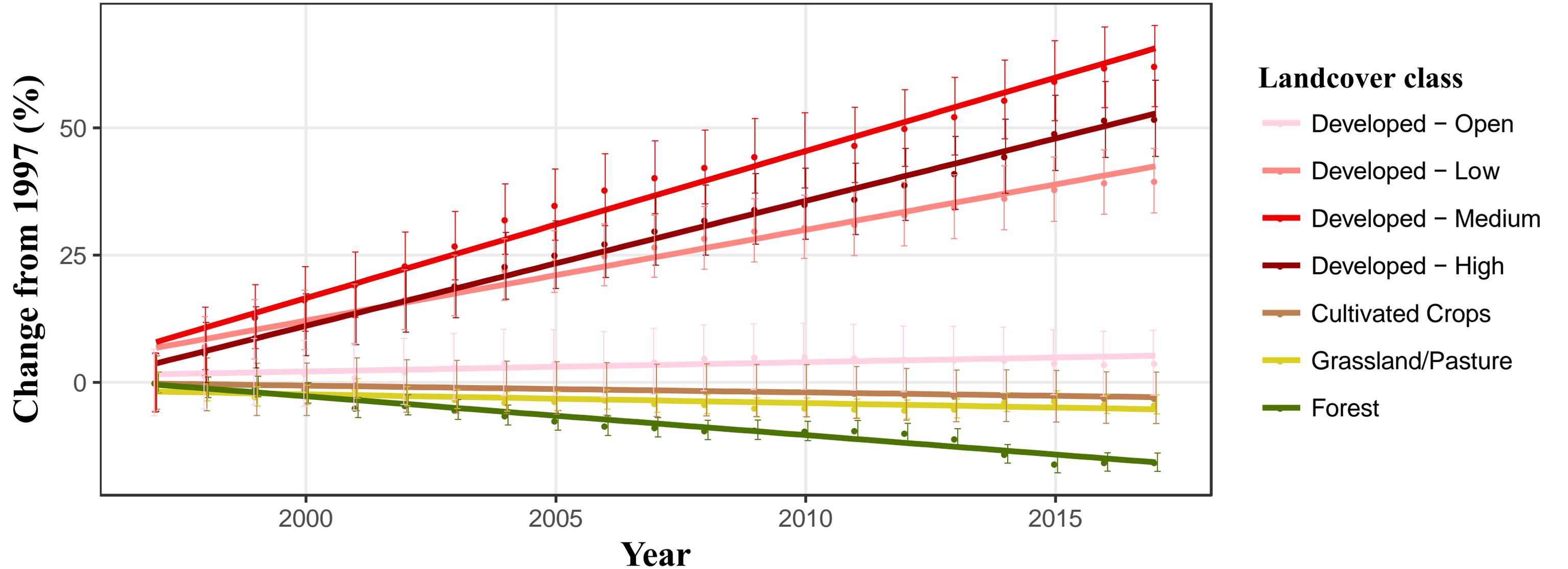
1997

2017

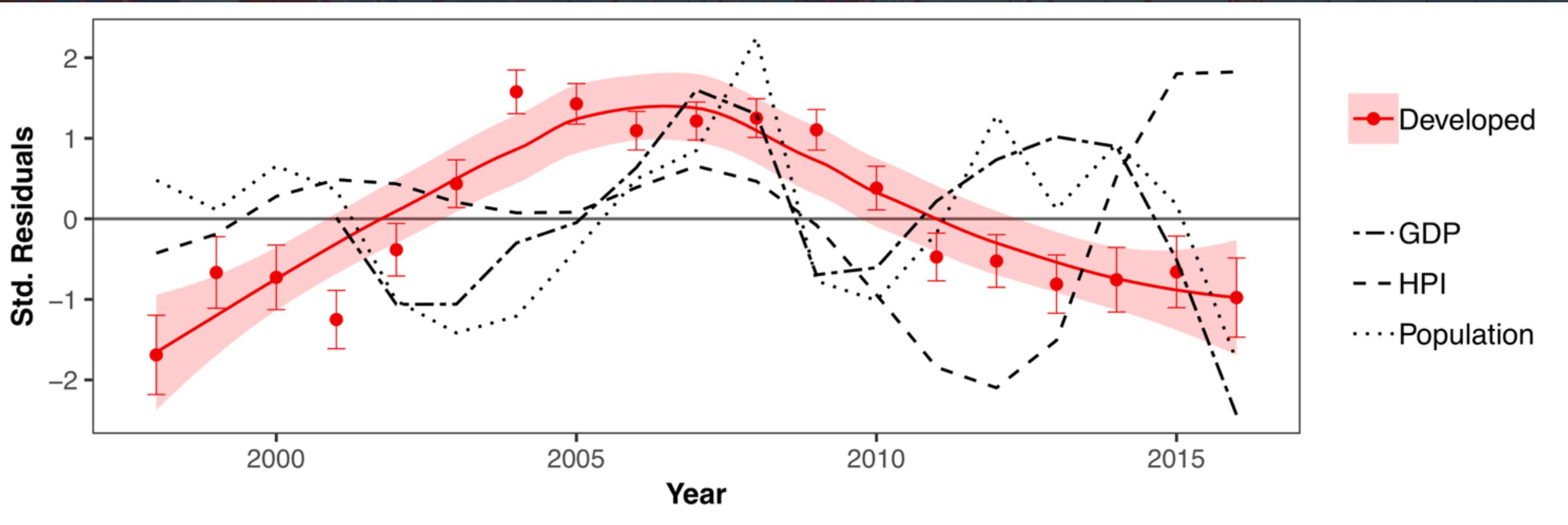
Change year



Land cover change rates



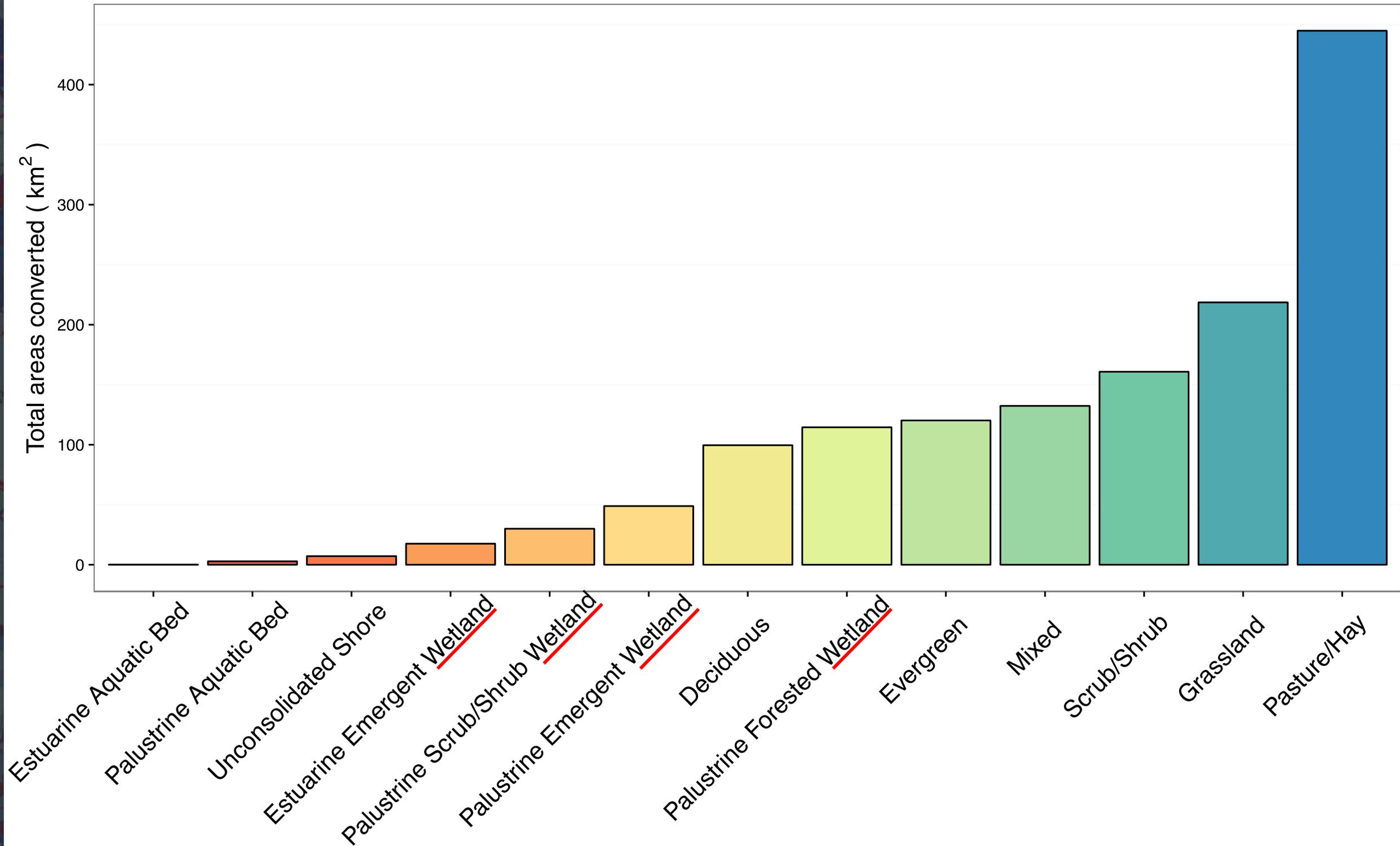
Urbanization and underlying socio-economic trends



Hakkenberg et al. (2019). *Int. J. Remote Sens.*

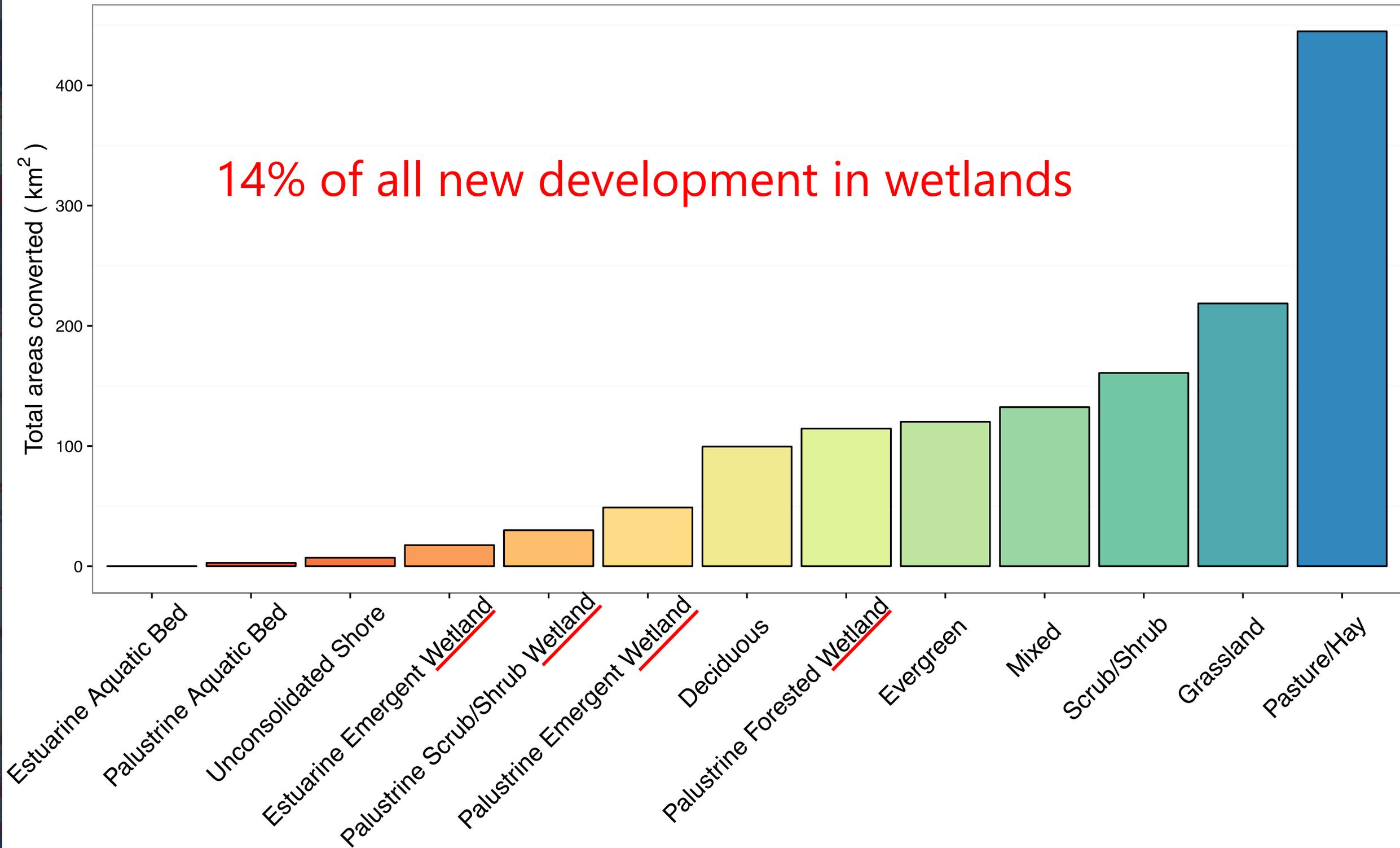
periodicity
time lags

Conversion of natural areas (1997–2017)



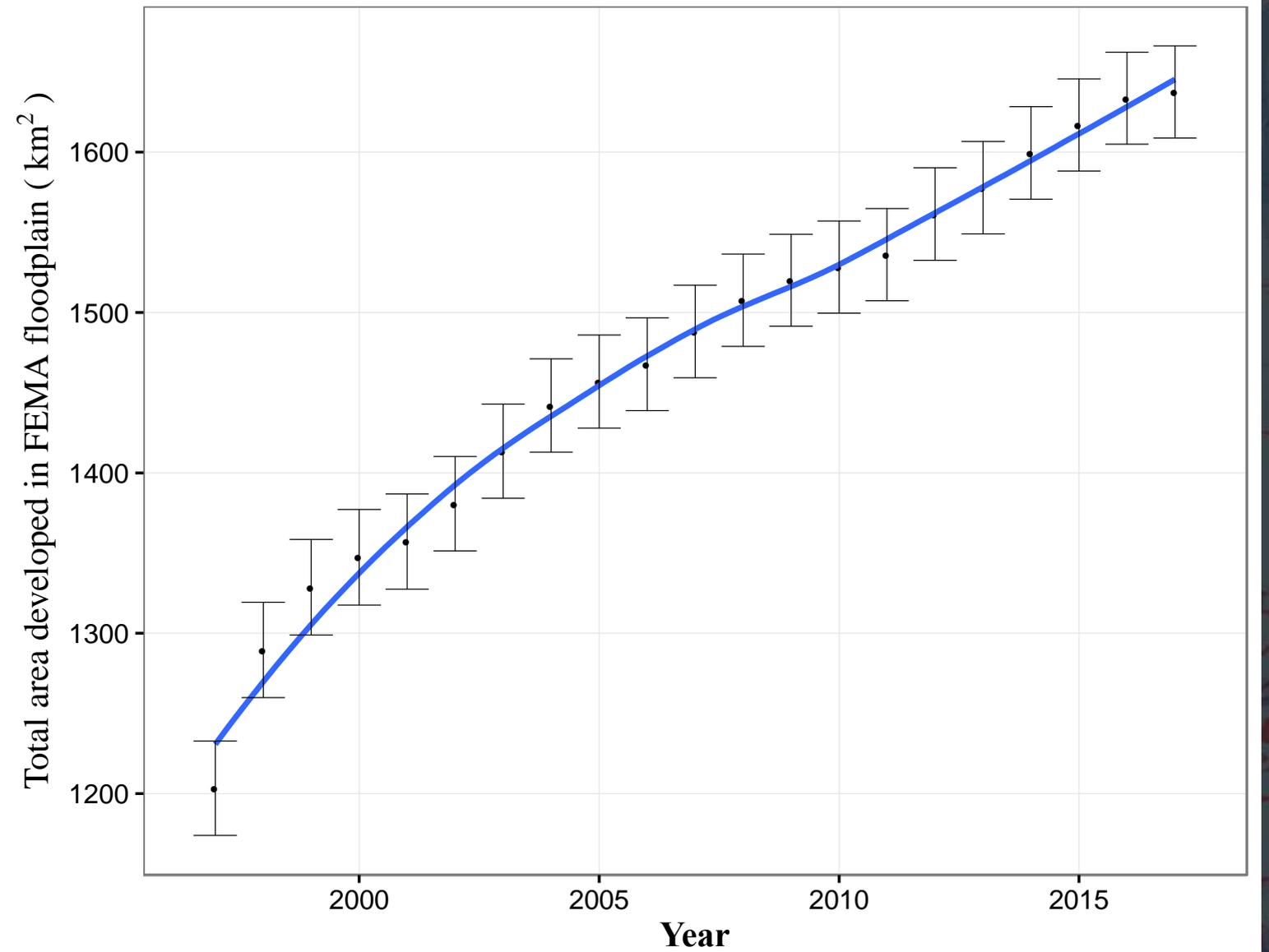
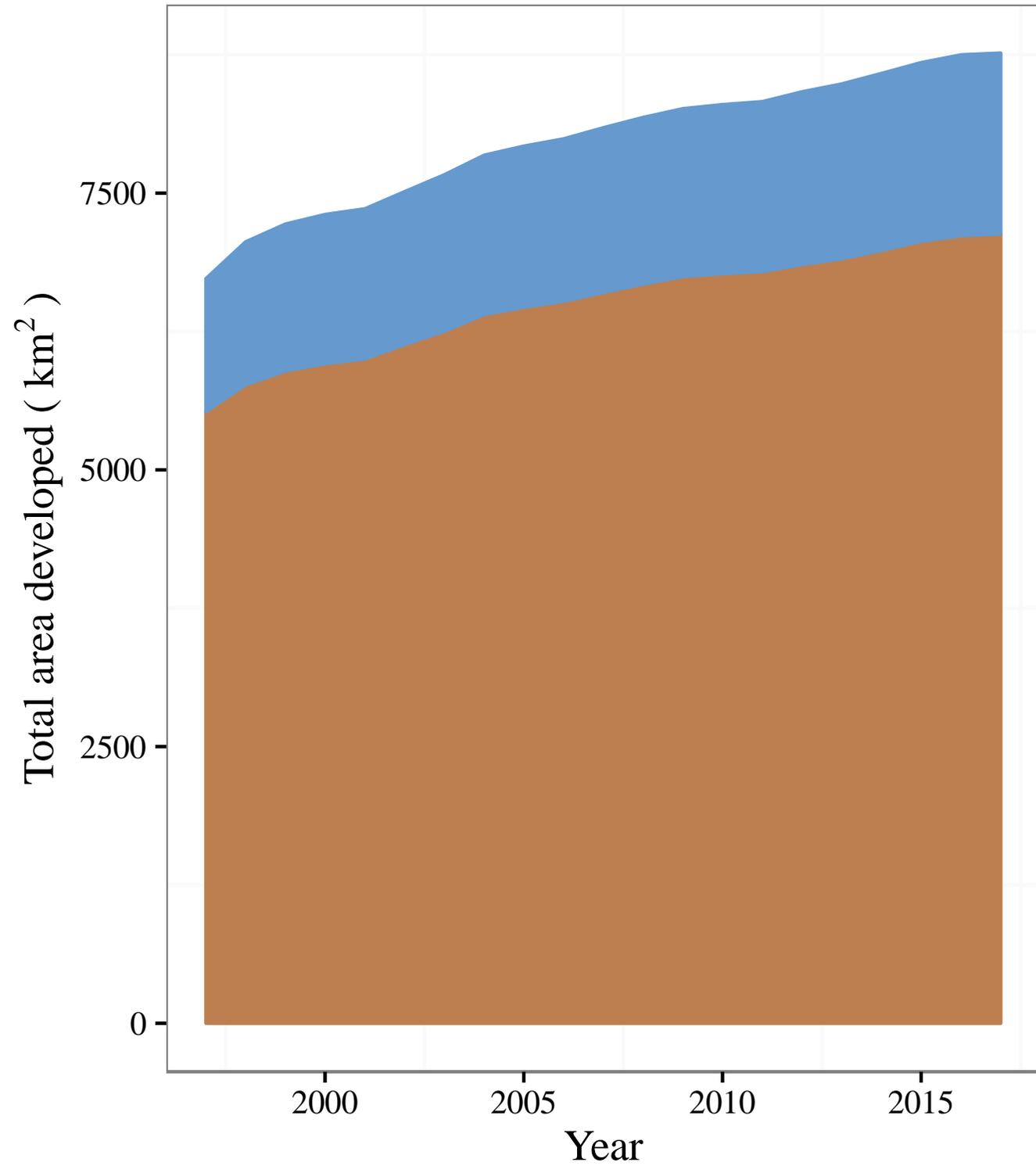
* Data from: NOAA's Coastal Change Analysis Program (C-CAP) land cover

Conversion of natural areas (1997–2017)

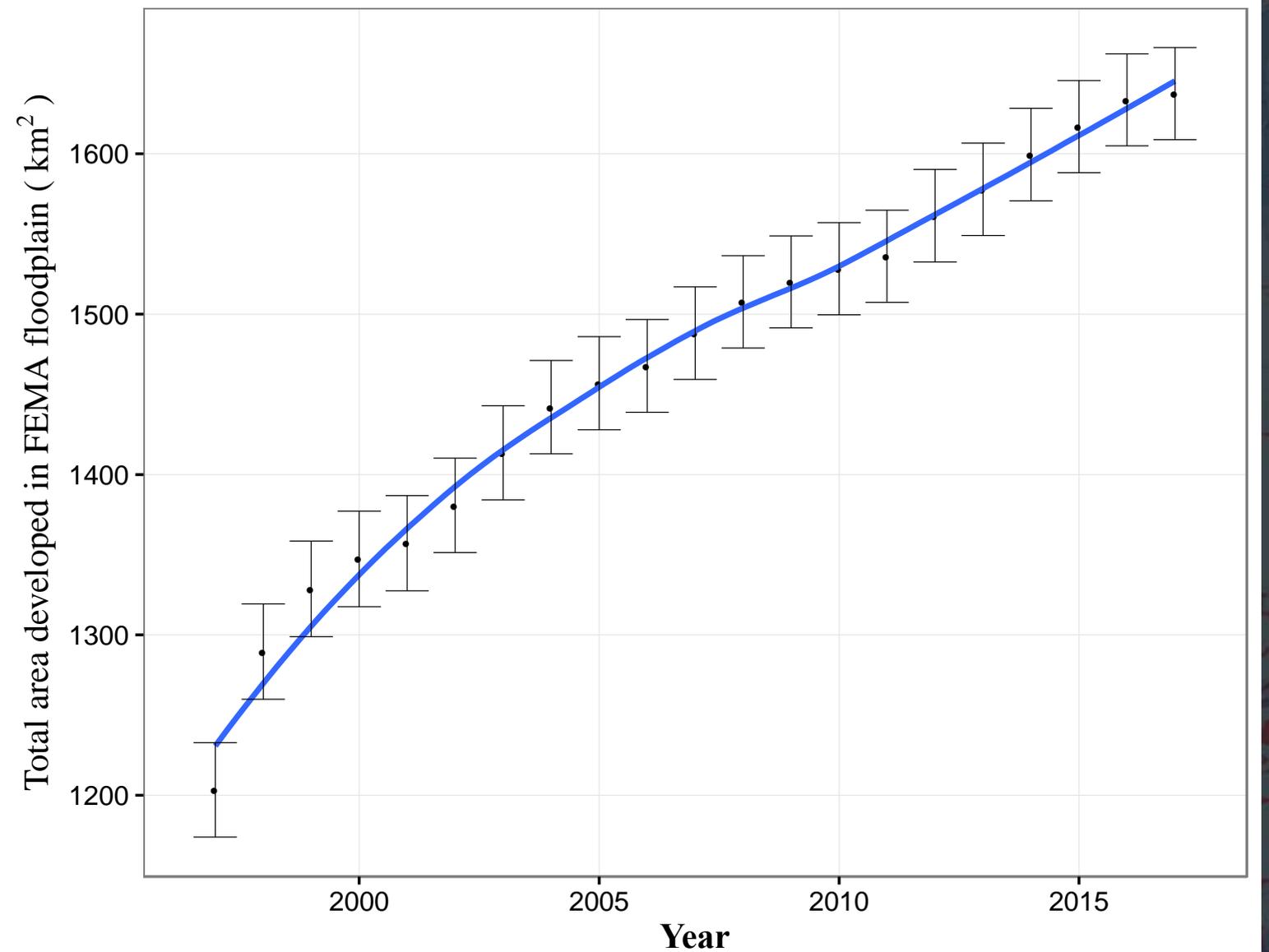
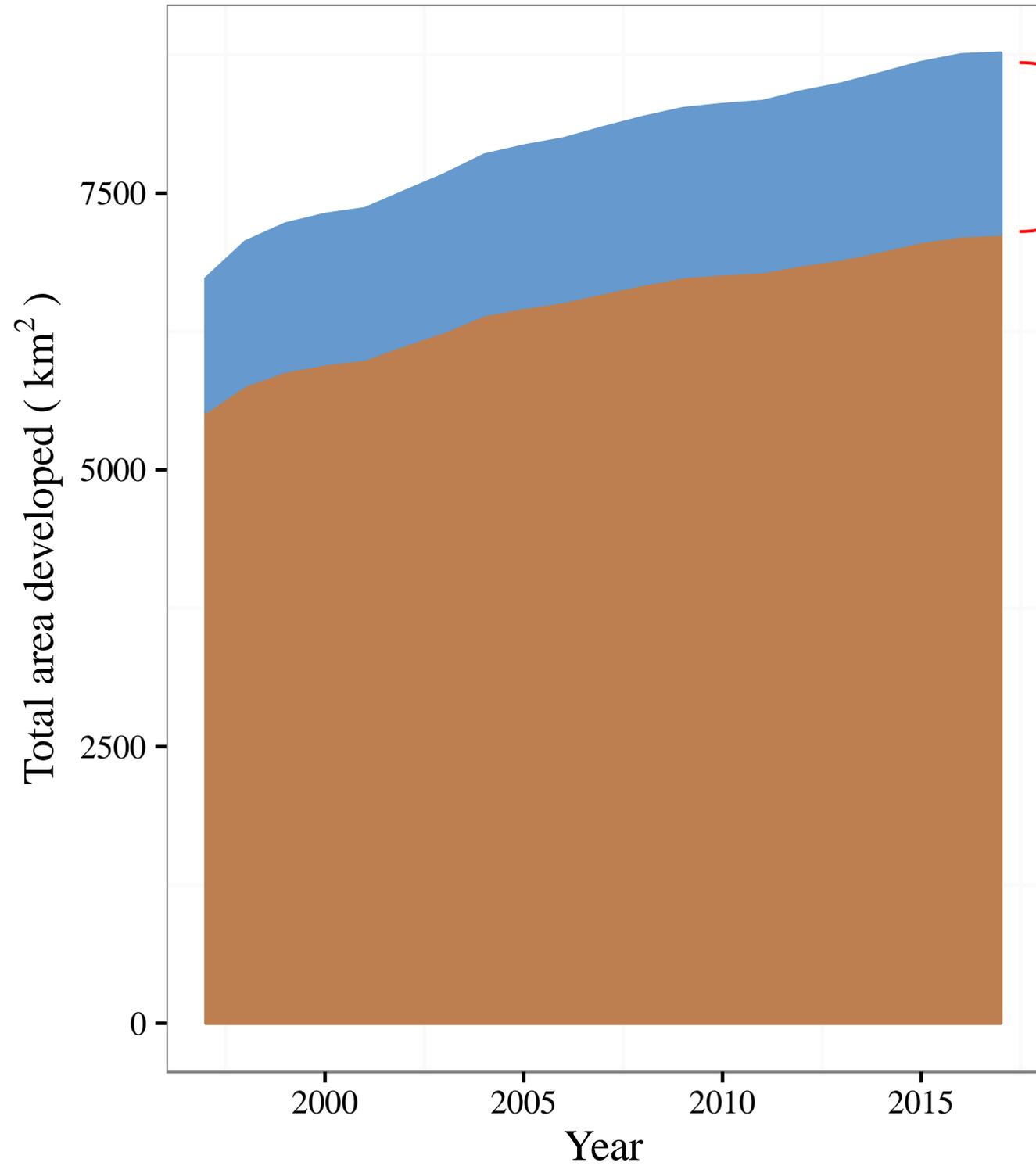


* Data from: NOAA's Coastal Change Analysis Program (C-CAP) land cover

Development in the FEMA 100yr Floodplain



Development in the FEMA 100yr Floodplain

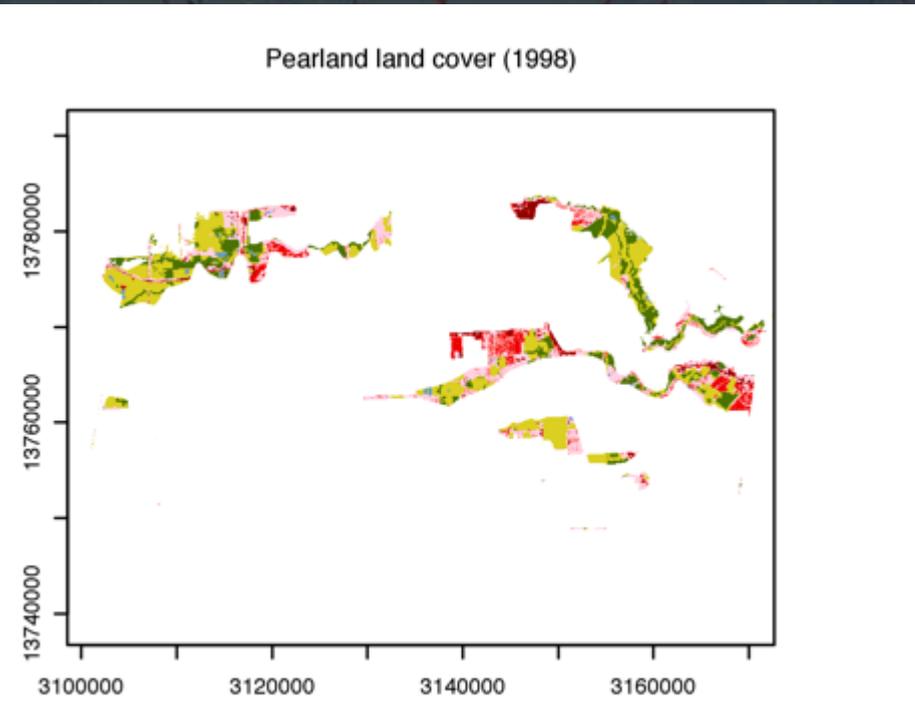
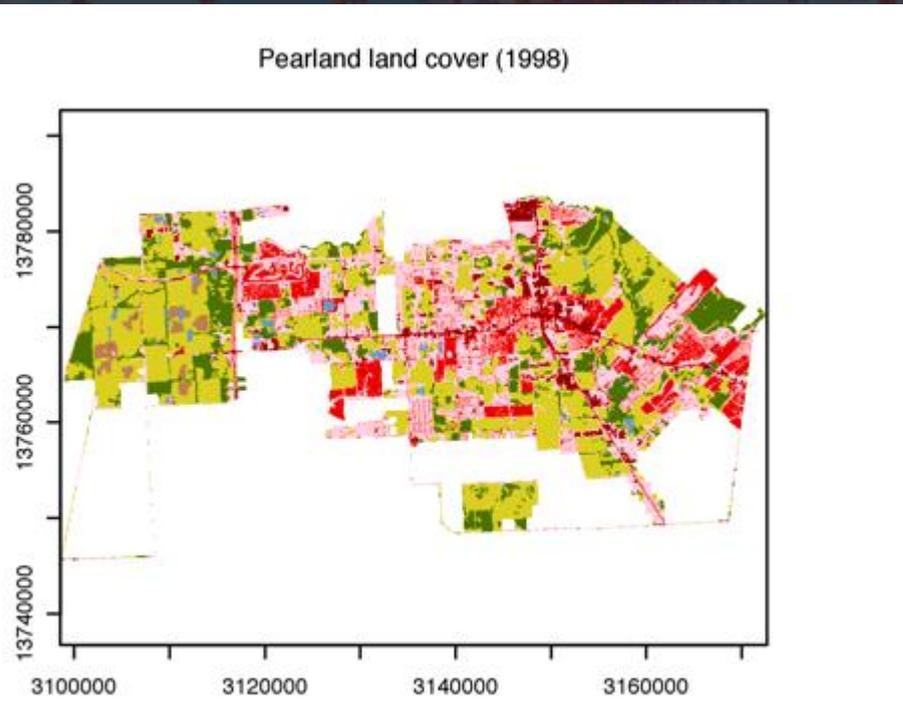


Development in the FEMA 100yr Floodplain - Pearland

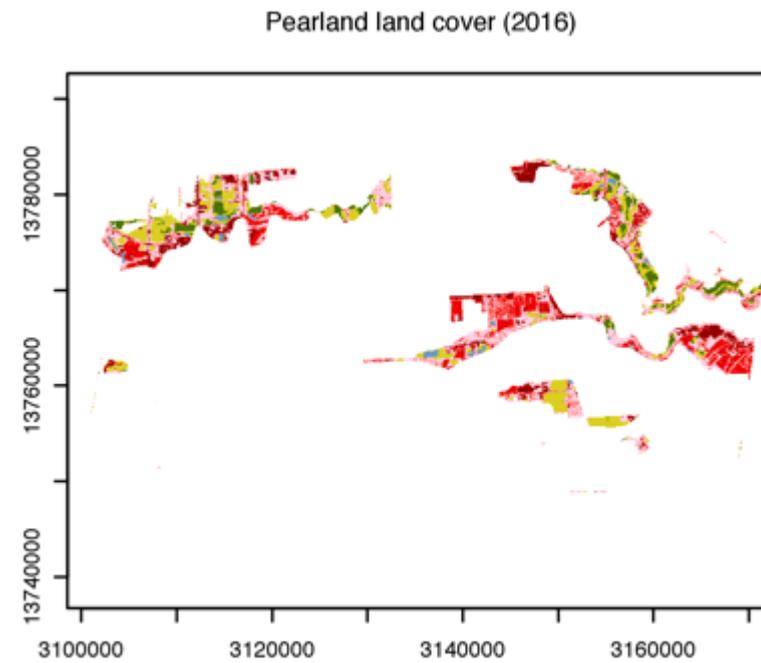
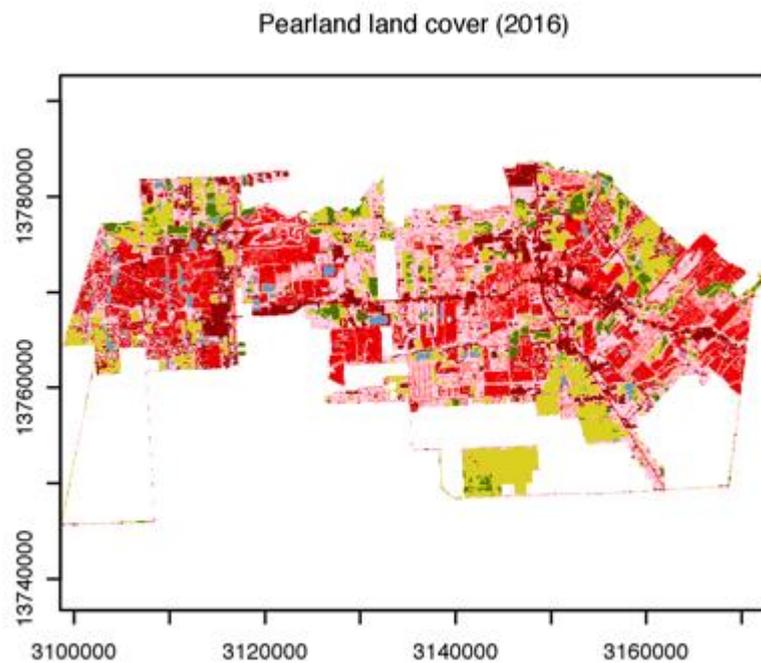
Jurisdiction

Portion of jurisdiction in FEMA 100yr Floodplain

1998



2016

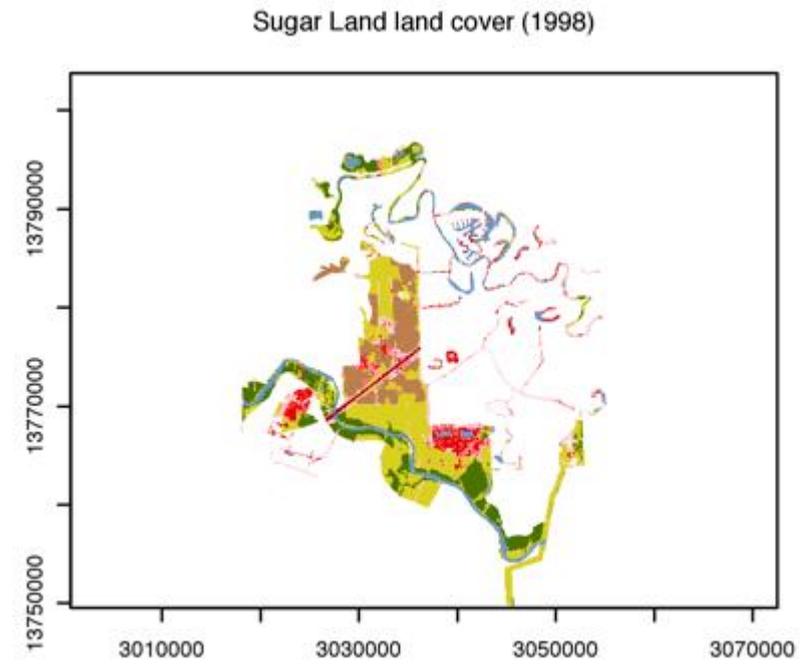
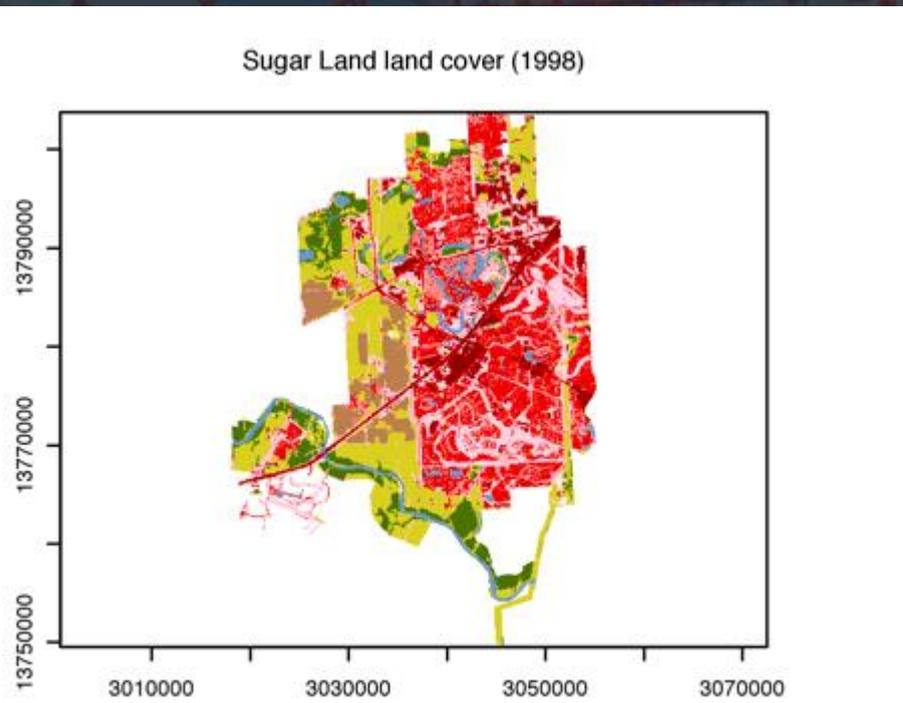


Development in the FEMA 100yr Floodplain - Sugarland

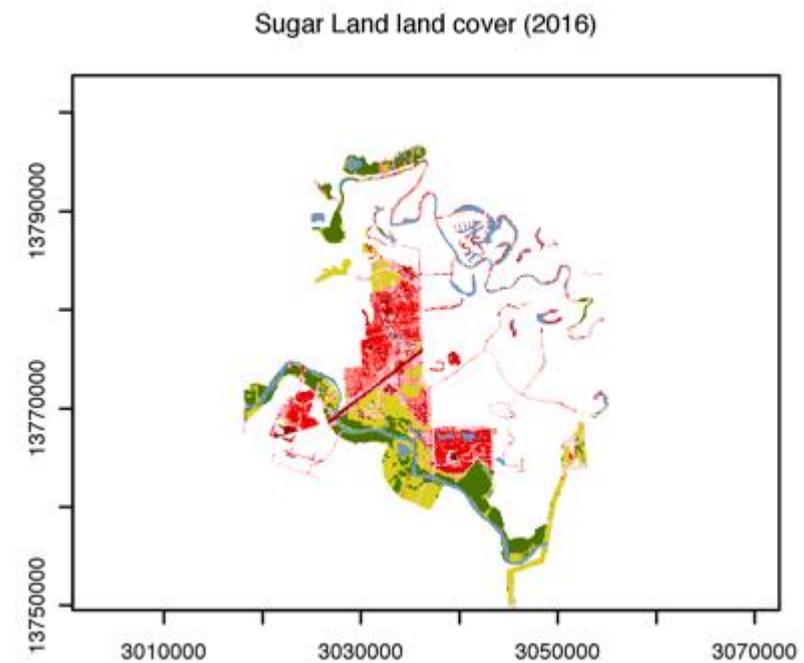
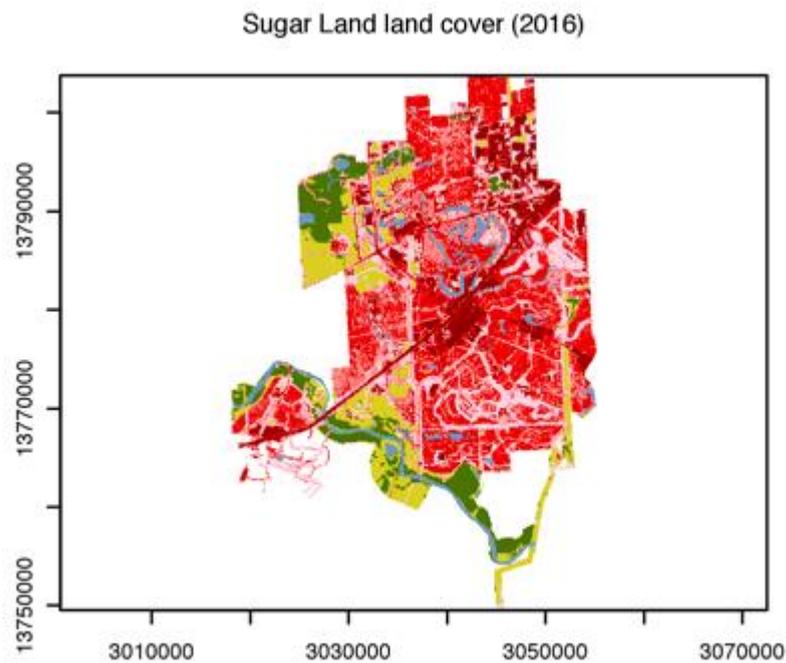
Jurisdiction

Portion of jurisdiction in FEMA 100yr Floodplain

1998



2016

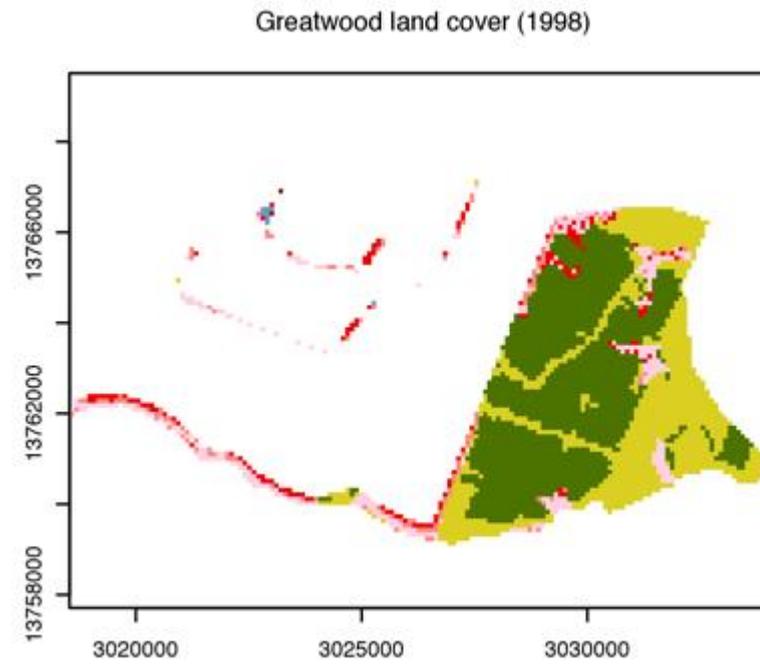
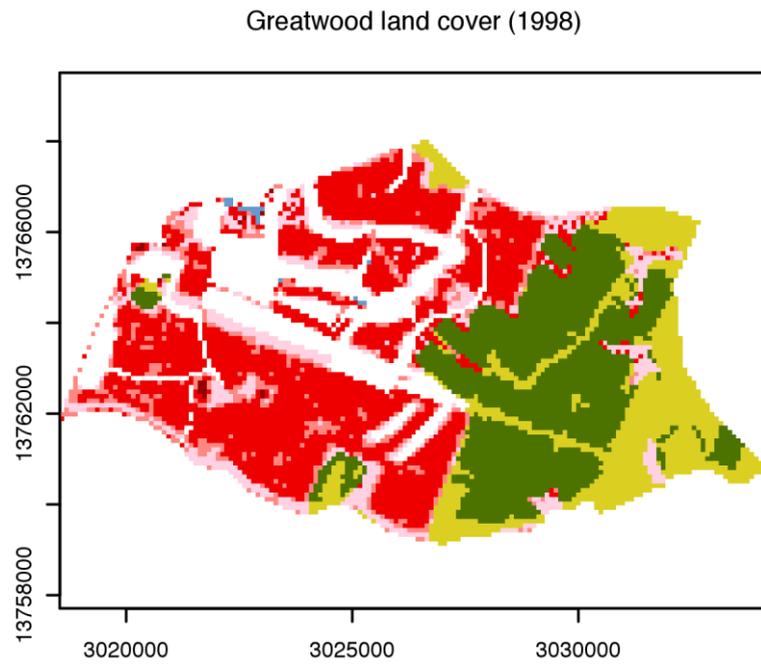


Development in the FEMA 100yr Floodplain - Greatwood

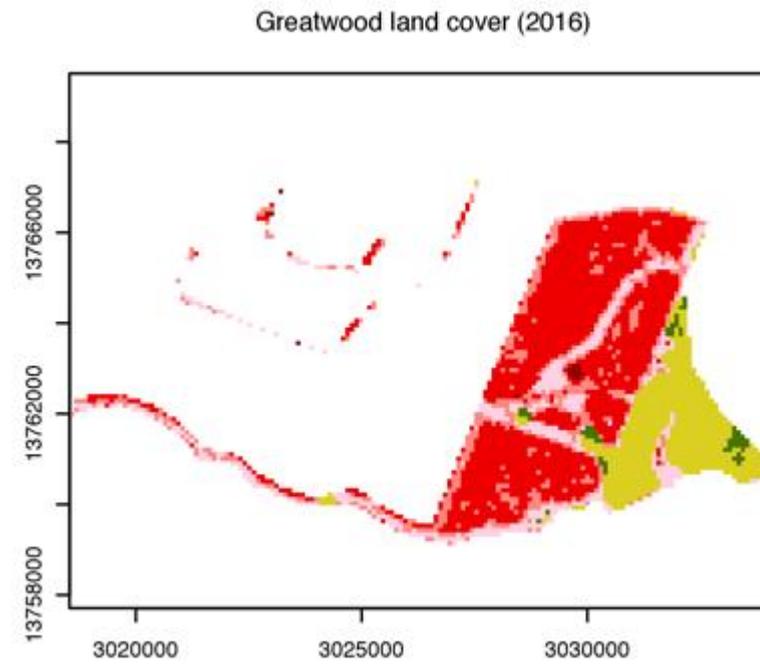
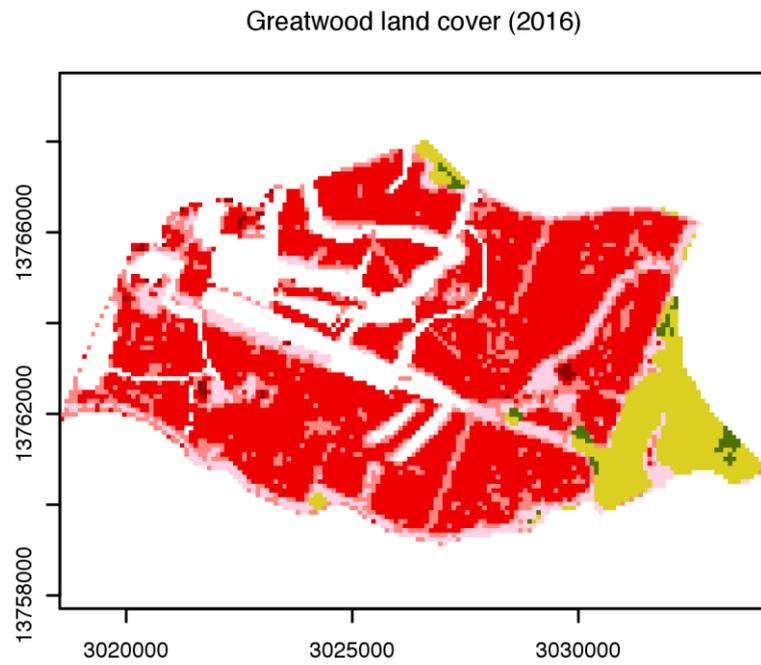
Jurisdiction

Portion of jurisdiction in FEMA 100yr Floodplain

1998



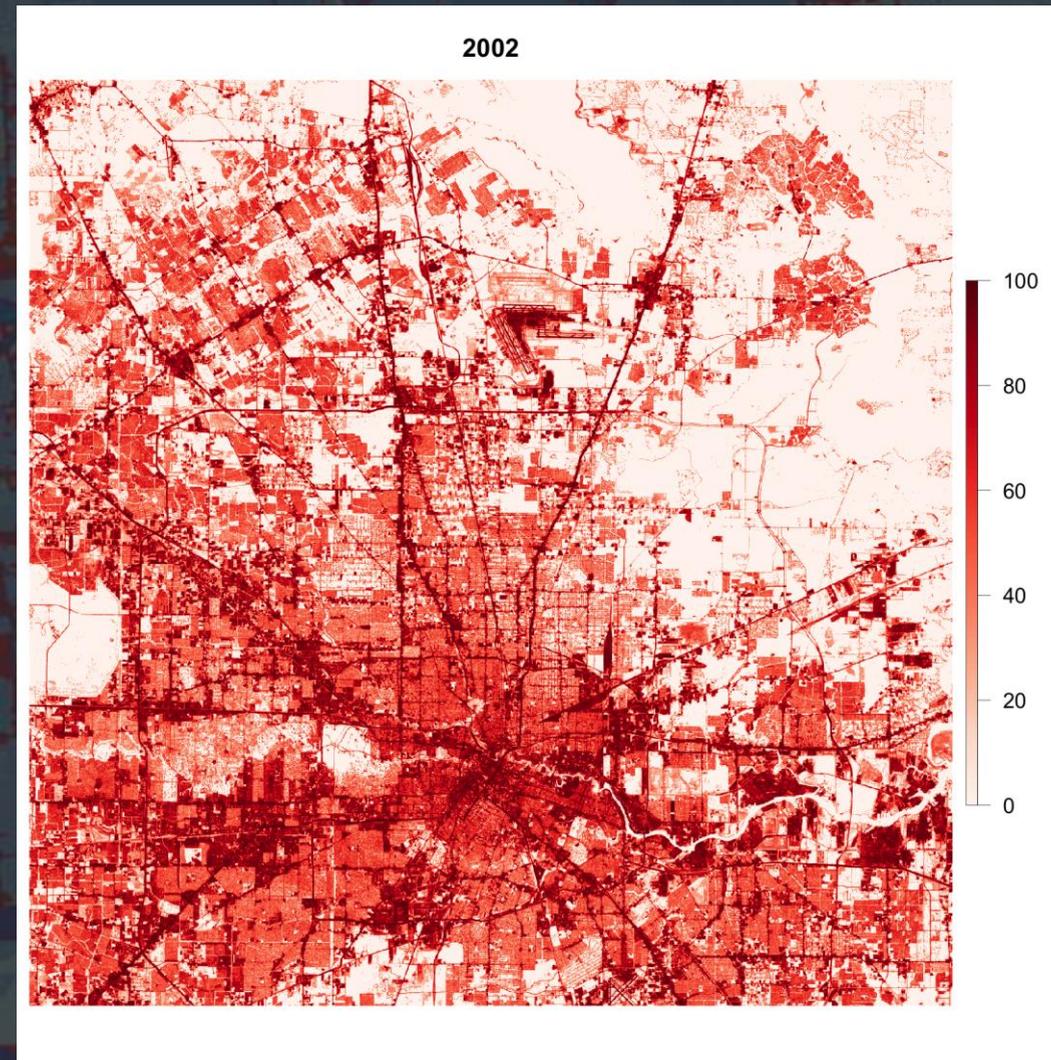
2016



Urbanization time series: 1997:2018

2.

Subannual percent impervious



Subannual continuous fields impervious fractional cover

Temporal extent:

22 years (1997-2018)

Spatial resolution:

30x30 m

Spatial extent:

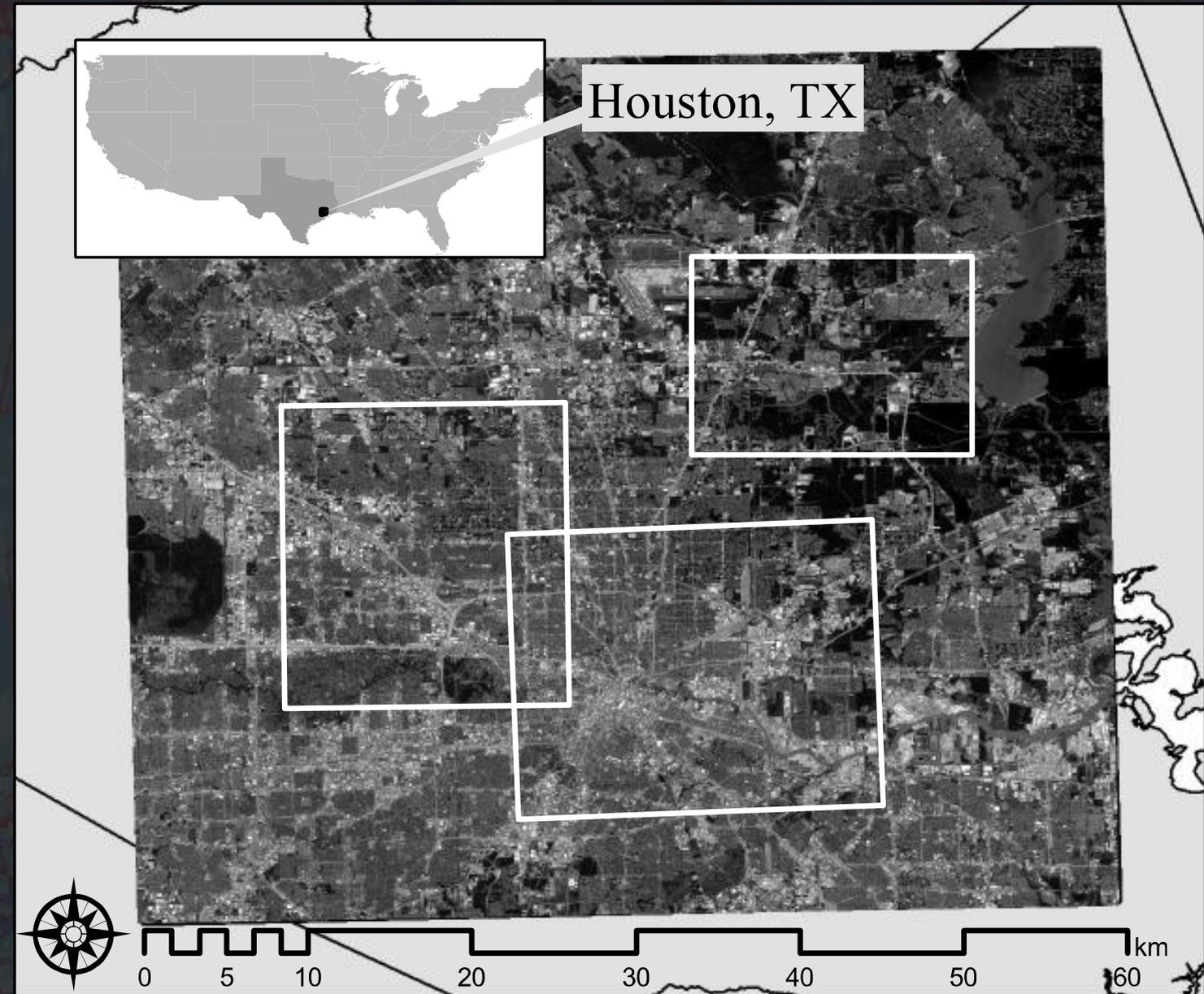
2720 km²

Temporal resolution:

subannual (~3/year)

Thematic resolution:

continuous impervious (0-100%)



Automatic Adaptive Signature Generalization for regression (AASGr)

Image (date 1)

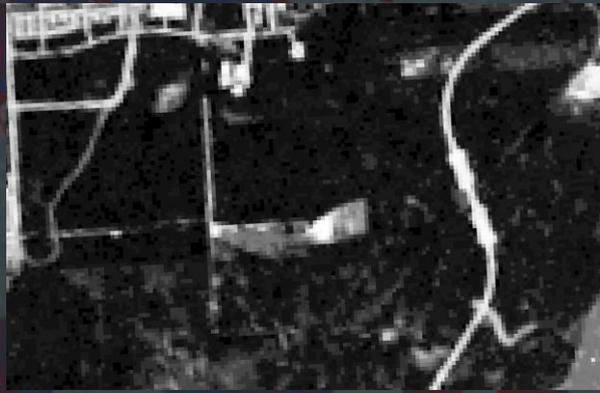


Image (date 2)

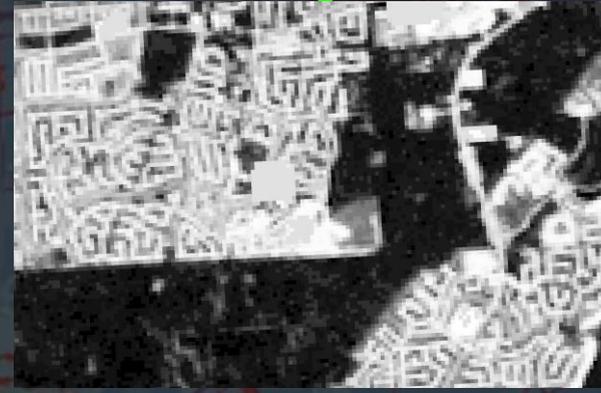


Image Difference

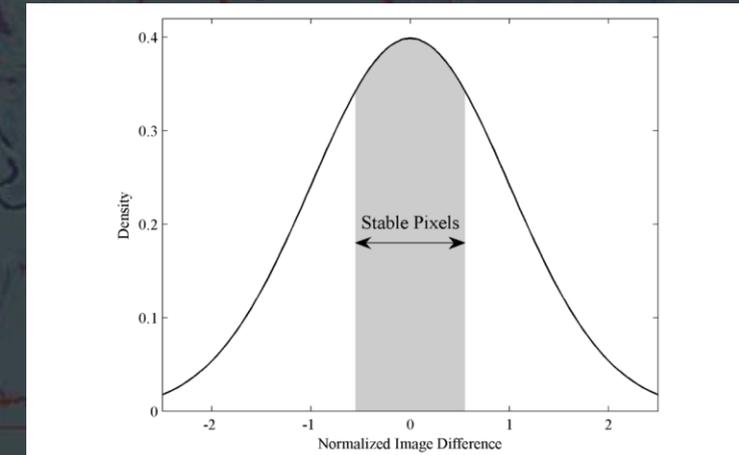


Figure 1. Identification of stable pixels based on image difference histograms ($I_2 - I_1$) for each land cover class. Stable pixels are those within a given distance from the mean (μ_k) of class k .

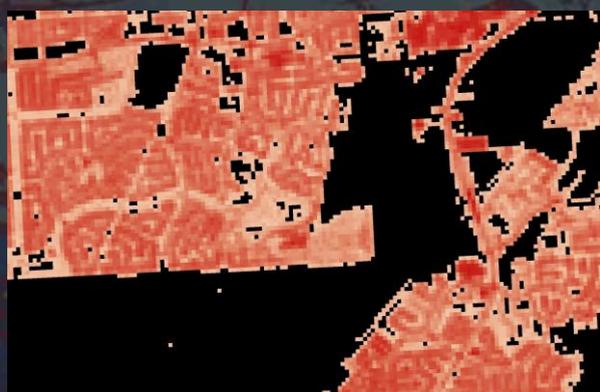
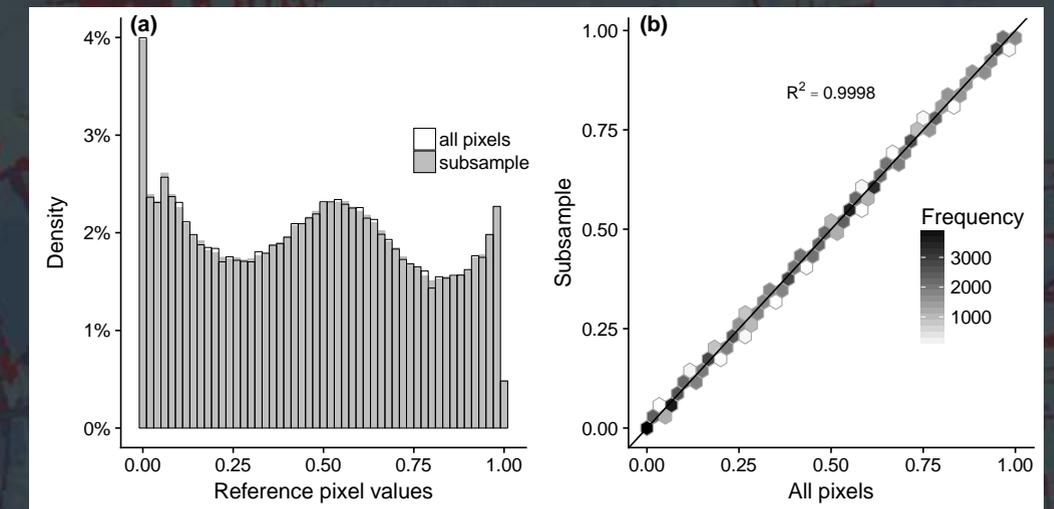
Confidence (date 2)



Reference Map (date 1)



Randomized subsampling

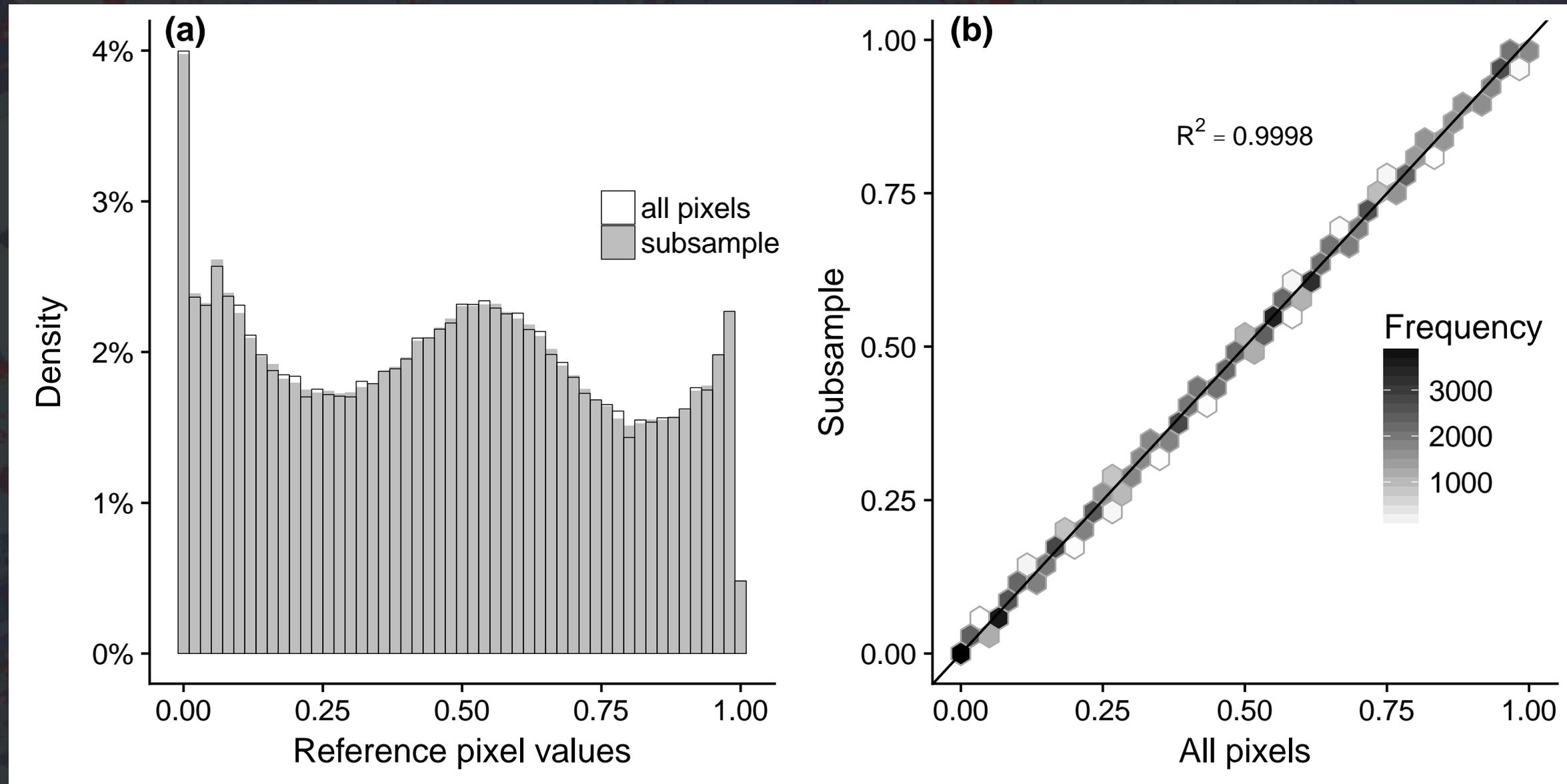


Prediction (date 2)

Image (date 2)

Automated training data subsampling

- (1) multi-band stable sites
- (2) proportional allotment
- (3) random stratified sampling



Automatic Adaptive Signature Generalization for regression (AASGr)

Image (date 1)

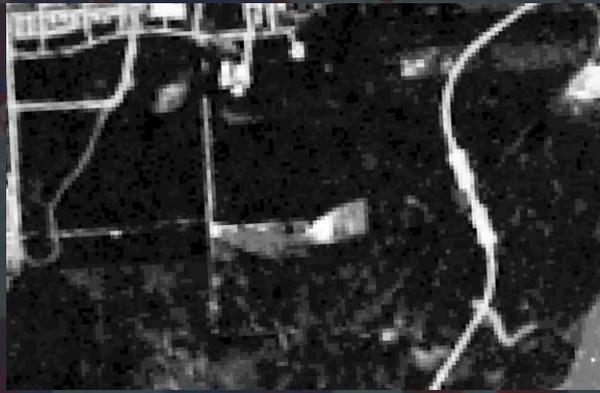


Image (date 2)

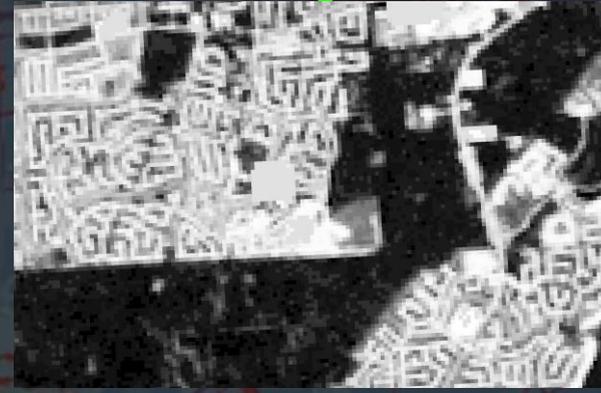


Image Difference

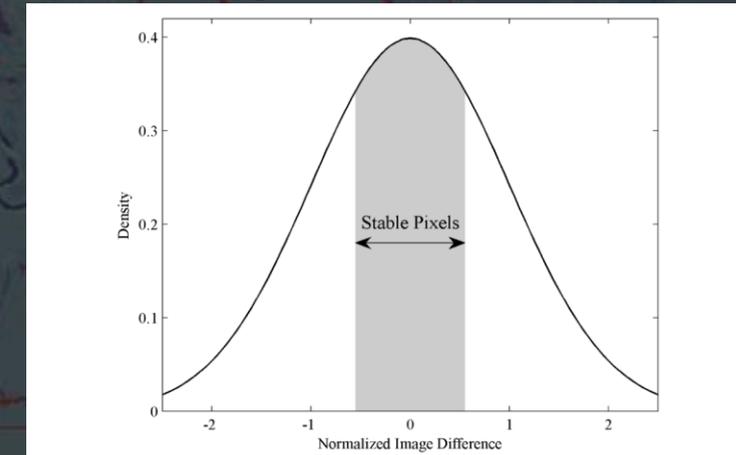


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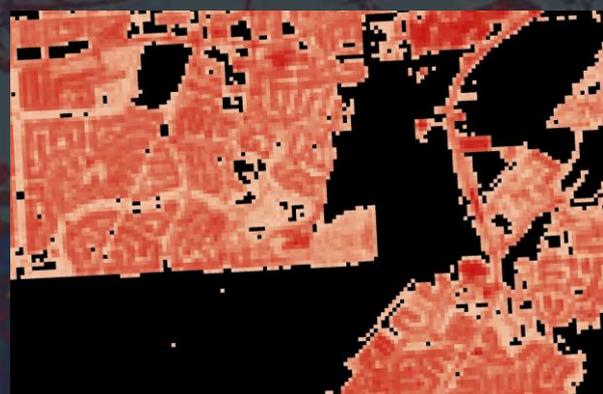
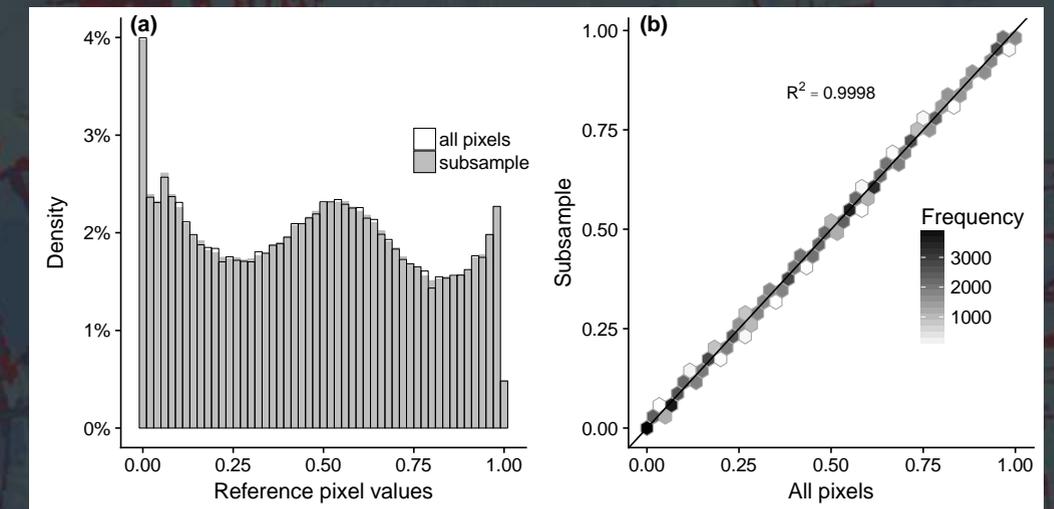
Confidence (date 2)



Reference Map (date 1)



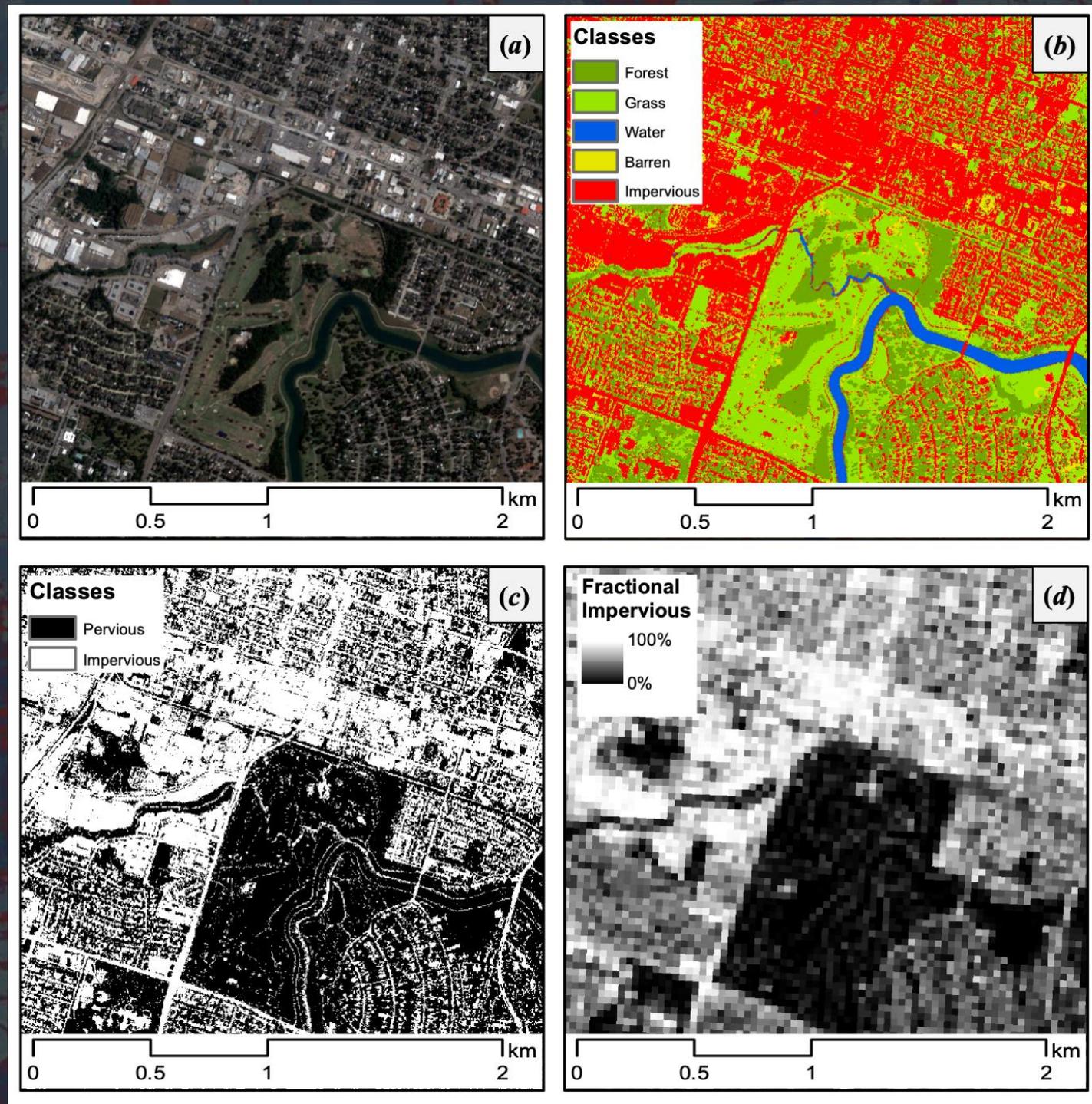
Randomized subsampling

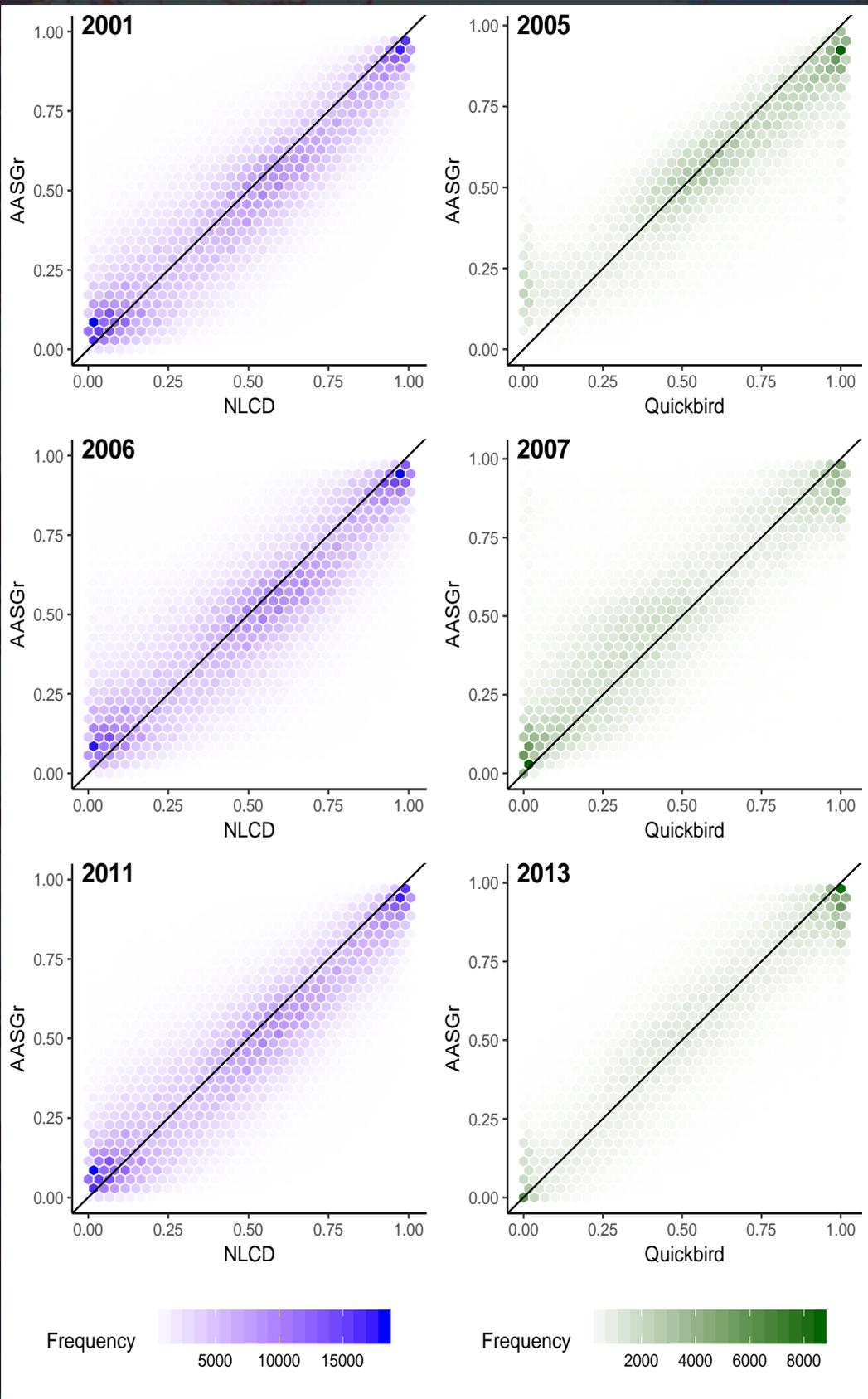


Prediction (date 2)

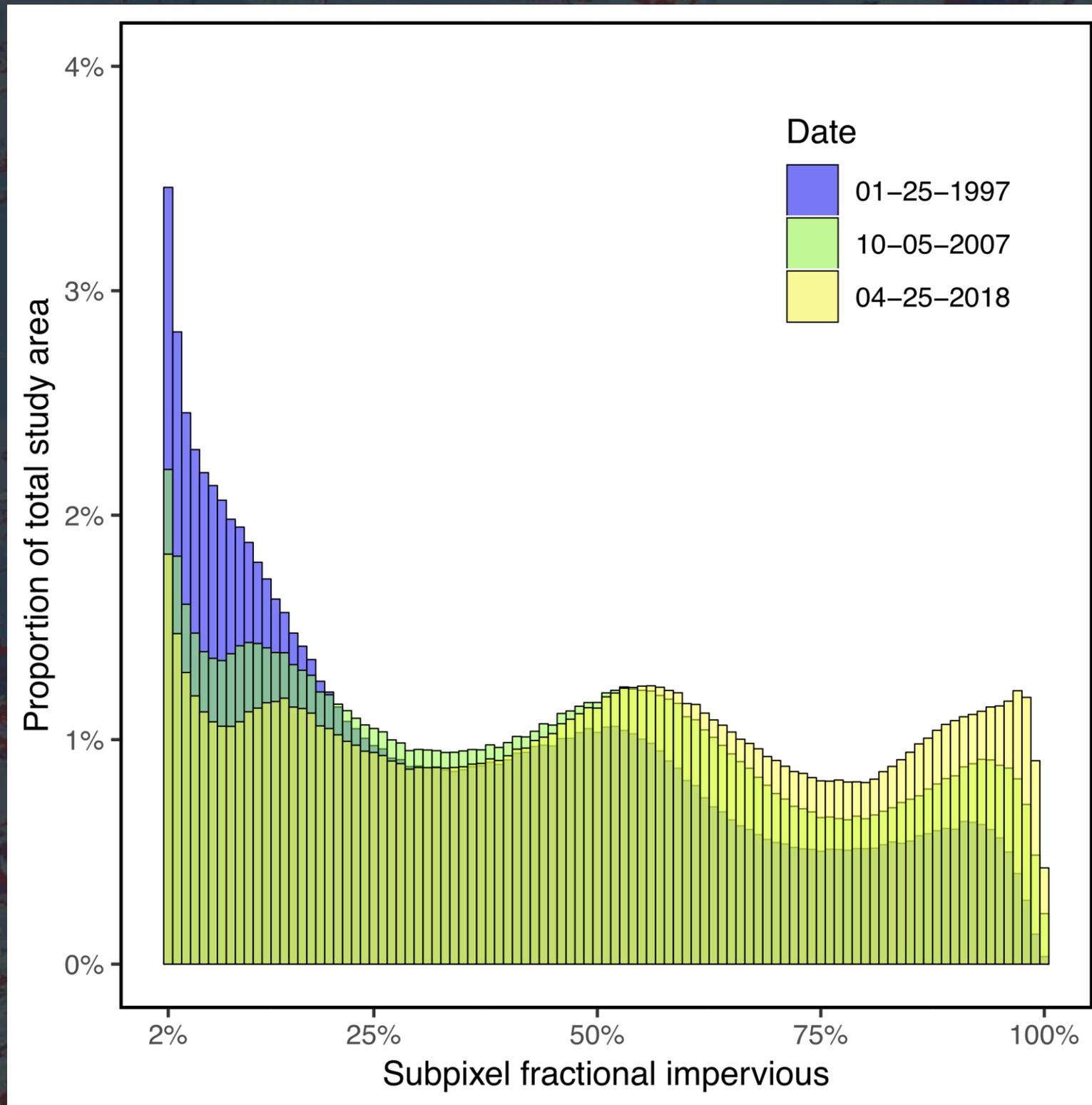
Image (date 2)

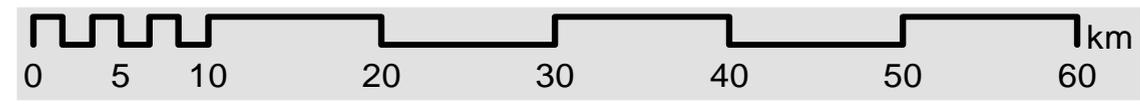
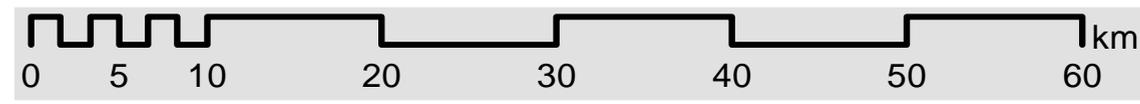
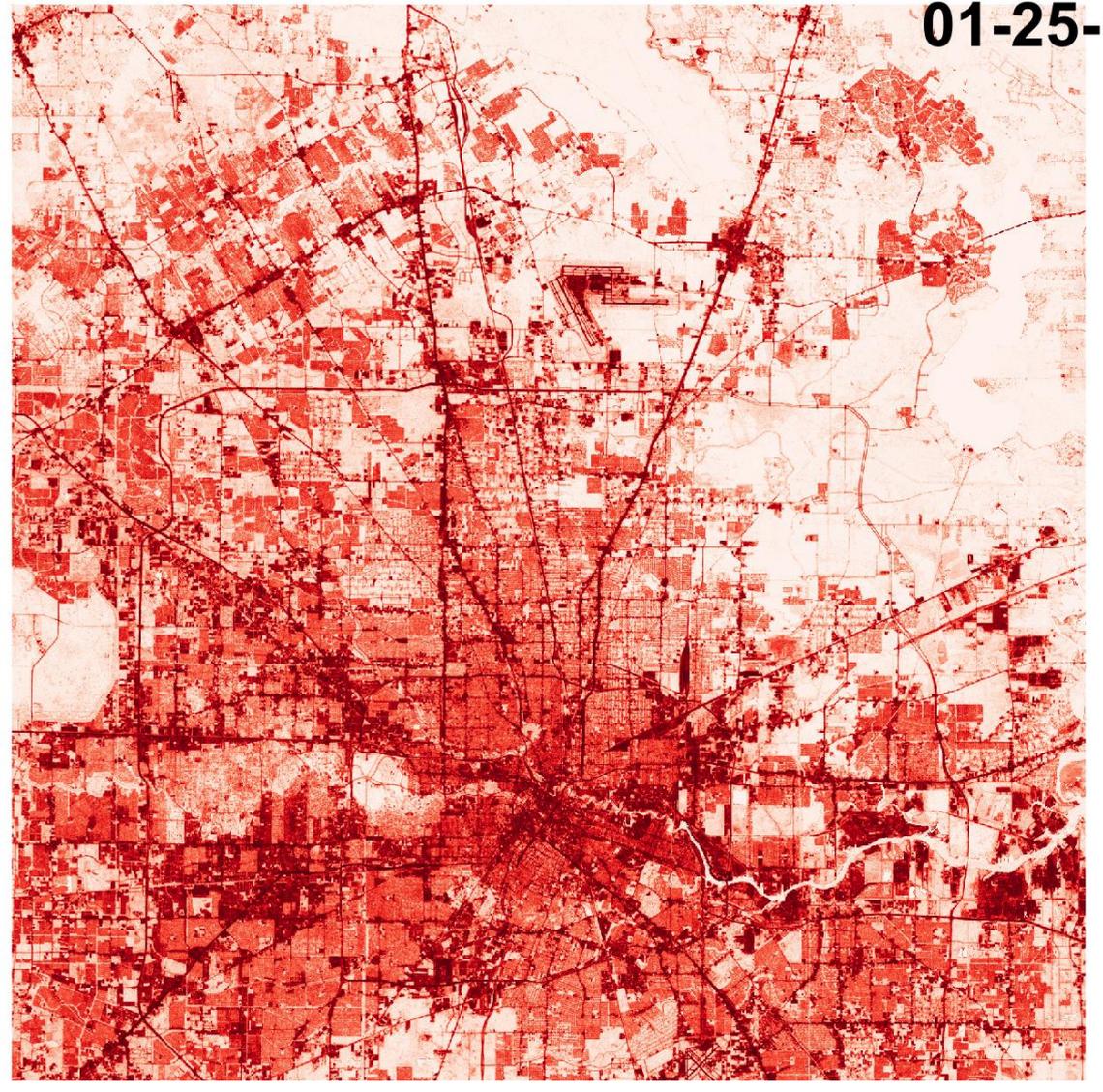
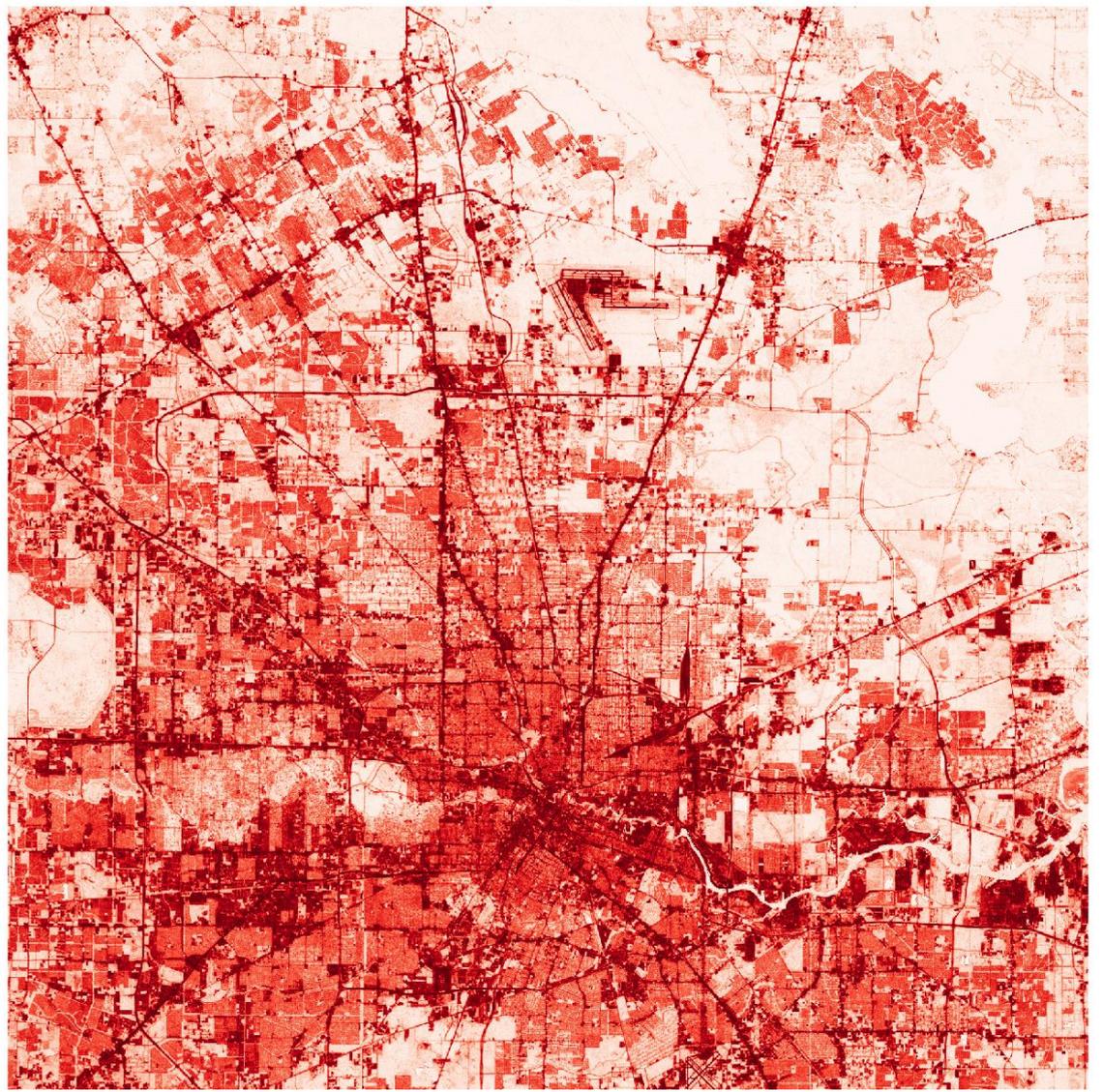
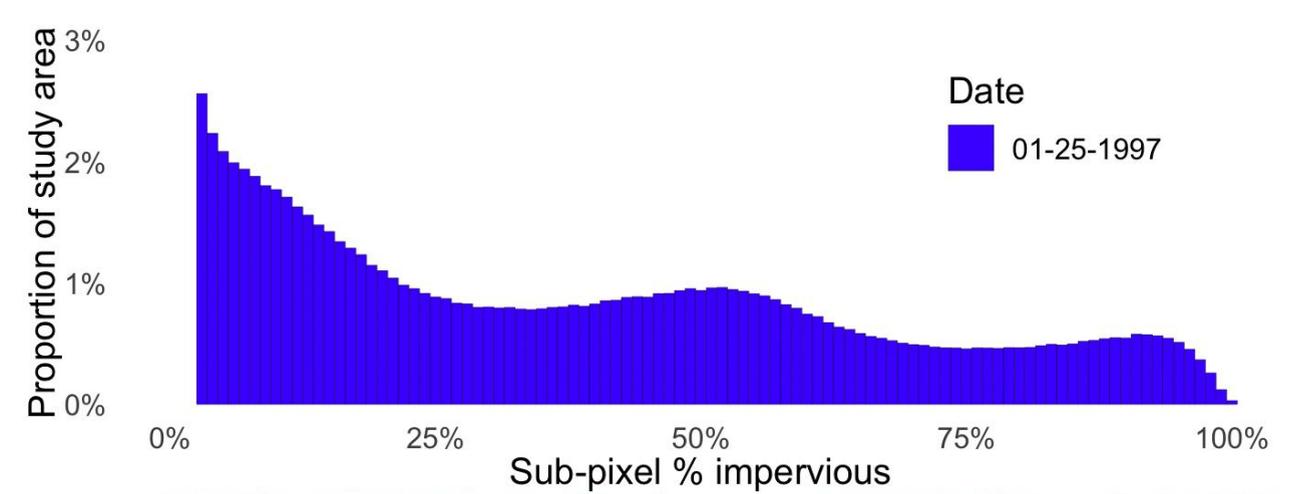
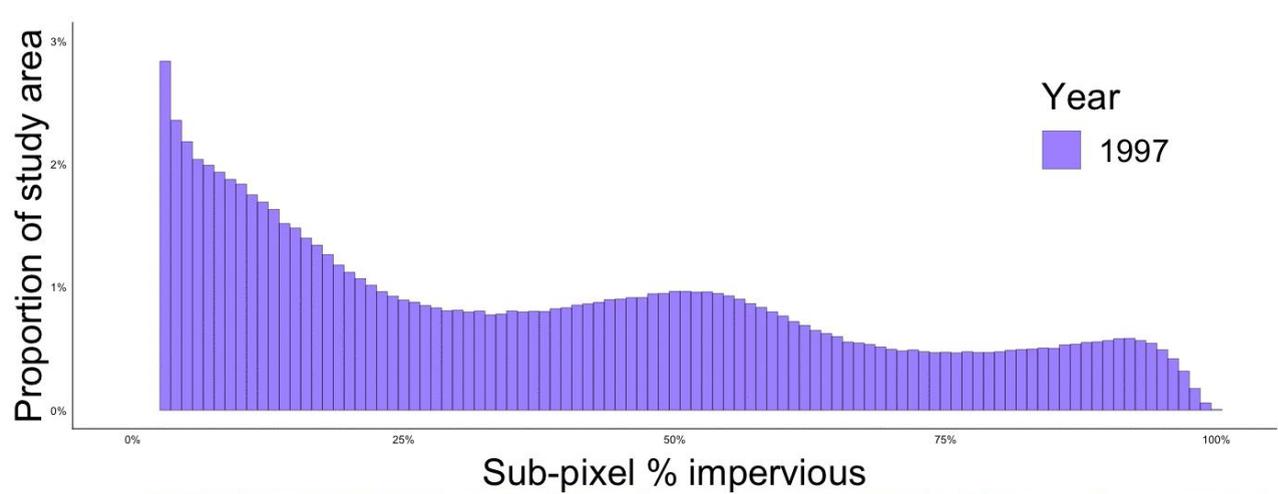
Accuracy Assessment





	Year	adj-R ²	RMSE	MAE	bias
NLCD	2001	0.82	0.14	0.09	0.01
NLCD	2006	0.77	0.16	0.11	0.02
NLCD	2011	0.77	0.16	0.11	-0.01
Quickbird	2005	0.72	0.15	0.11	-0.05
Quickbird	2007	0.80	0.14	0.11	0.03
Quickbird	2013	0.79	0.14	0.11	-0.01





Conclusions:

1. Automated model parameterization and prediction

- multi-band stable sites
- proportional allotment
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Conclusions:

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2. Discrete (urban classes) and continuous fields (% impervious)

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 - periodicity
 - abrupt transitions
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5. AASG R package

- Dannenberg, M.P., Hakkenberg, C.R. and C. Song. (2016). Automatic Adaptive Signature Generalization (AASG) in R. DOI: [10.17632/s7c3vfr84w.1](https://doi.org/10.17632/s7c3vfr84w.1)

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 - kinder.rice.edu/urban-data-platform

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 - socio-economics and demography
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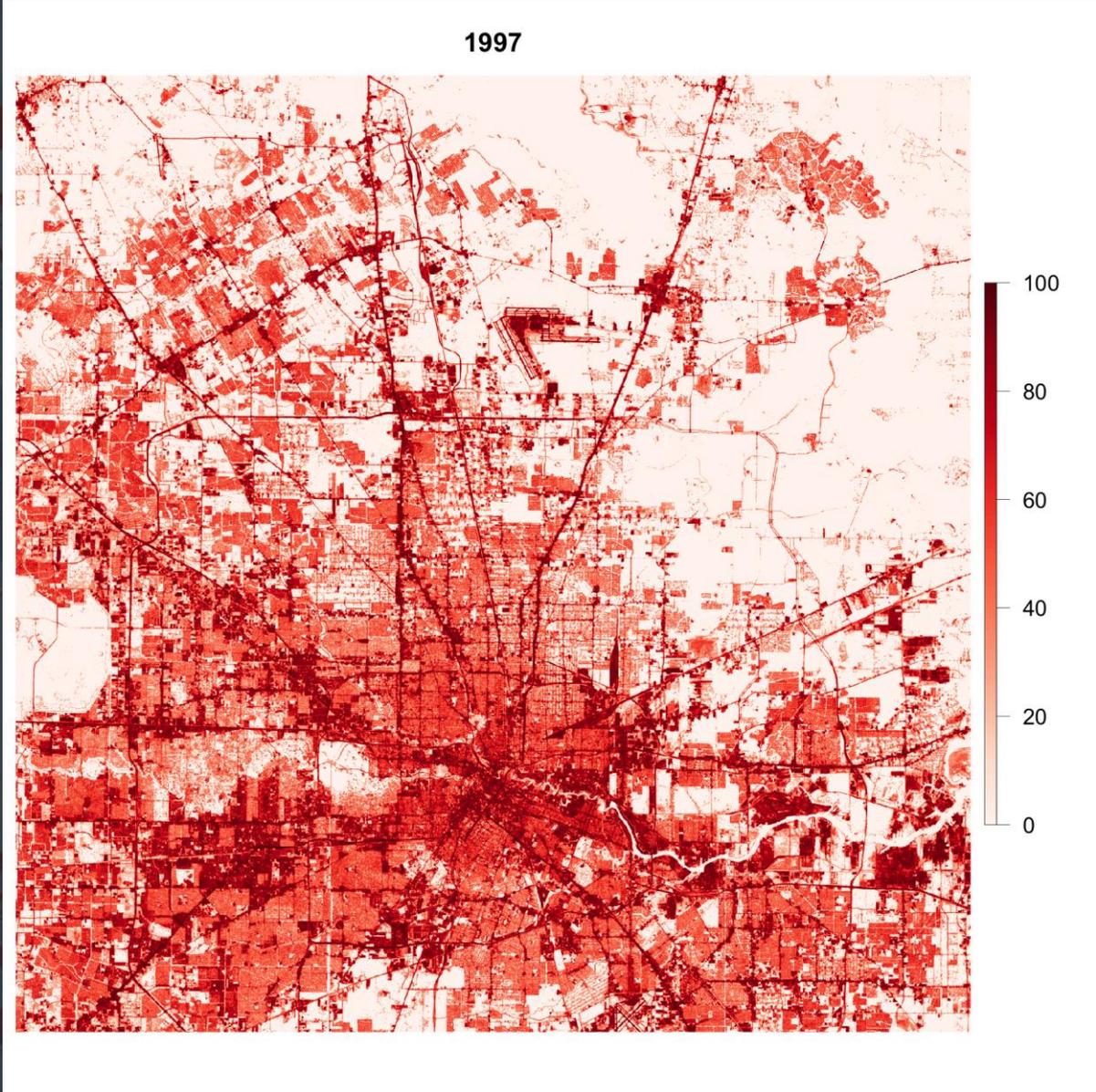
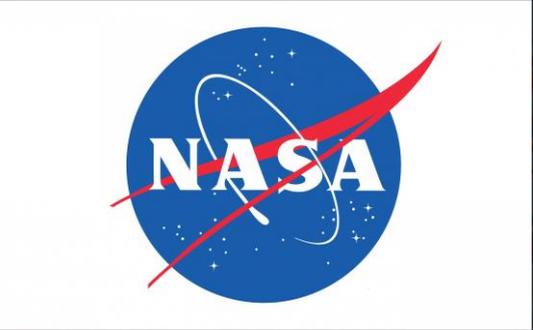


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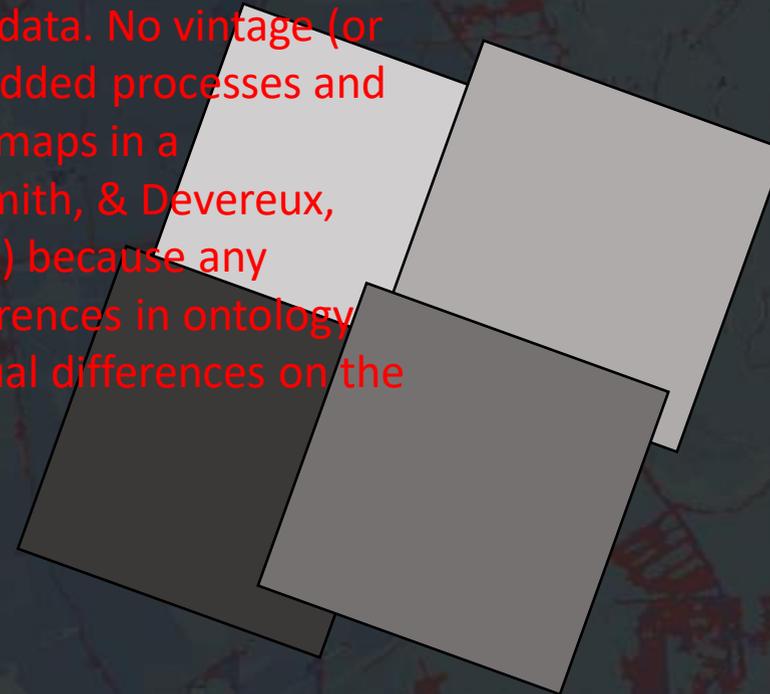


Subannual mapping of impervious surface in the Houston metropolitan area

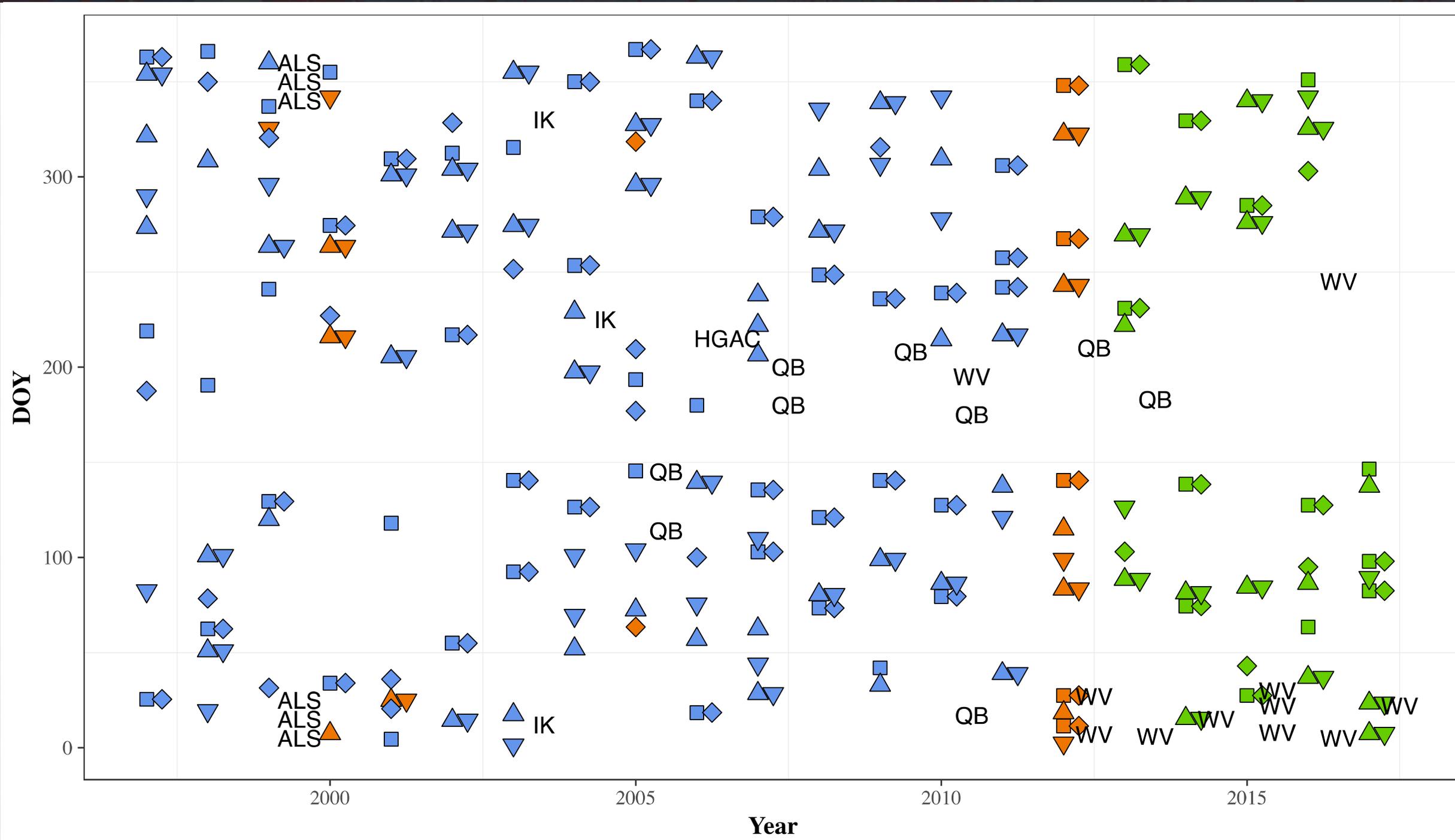
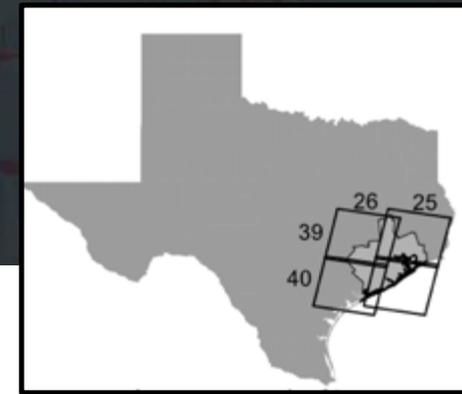


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Each LCLU map has a methodological and temporal vintage which is sometimes called an “ontology” (Comber, Fisher, & Wadsworth, 2005b). Ontologies are explicit specifications of an abstract representation of the world (Gruber, 1993; Guarino, 1995) like a map. In an LCLU mapping context they reflect choices over spatial, spectral, and radiometric data resolutions as well as the number and type of LCLU classes of the data. No vintage (or ontology) is ever the same because of the many embedded processes and assumptions (Comber et al., 2005b). Comparing LCLU maps in a post-classification change analysis is difficult (Fuller, Smith, & Devereux, 2003; Tewkesbury, Comber, Tate, Lamb, & Fisher, 2015) because any differences between them will reflect artefactual differences in ontology (Comber, Fisher, & Wadsworth, 2004), errors, and actual differences on the ground.



Distribution of Landsat imagery



WRS2 path/row

- 25 / 39
- ◇ 25 / 40
- △ 26 / 39
- ▽ 26 / 40

Landsat Sensor

- 5 TM
- 7 ETM+
- 8 OLI