Projecting the Urban Heat Island Effect Using Historical Weather Patterns and Land Cover

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Abstract

An Urban Heat Island is a metropolitan area with higher air and surface temperatures than surrounding areas. The Urban Heat Island Effect (UHIE) is a relative measure of the heat in urban heat islands. This research study investigates how developed land cover and weather trends can be used to forecast the UHIE with two distinct modeling frameworks. Projections of future conditions can prepare scientists and communities to take greener initiatives and adapt their lifestyle to preserve the Earth. The study focuses on the Greater Austin Region (TX, USA) for initial feasibility, but aims to extend these methods to a national or global scale. The first technique uses machine learning (Keras sequential model) to identify correlations between factors closely linked to the UHIE. The tested factors were air and surface temperature, relative humidity, soil moisture, and population growth. Evident correlations were found and used to begin training a predictive model (artificial neural network). The second technique uses developed softwares in QGIS Modules for Land Use Change Evaluation (MOLUSCE), high resolution satellite imagery provided by Multi-Resolution Land Characteristics land cover/land use data, and distance from roadways and inland water bodies data in order to accurately predict the possible changes in 2022 to the Greater Austin Region. Major limitations throughout the research process include regional & temporal data inconsistencies, the narrow scope of factors and geographic region, and the time constraint of the NASA SEES internship. Given ample time and data, these analyses can be used in green efforts to moderate and reduce the causes of UHIE. They can also aid in further investigating water contamination, energy consumption, and human health, and make larger scale environmental simulations possible.

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NASA SEES UHIE Team

THE GLOBE PROGRAM

Global Learning and Observations to Benefit the Environment

STEM Enhancement in Earth Science

SEES

SUMMER HIGH SCHOOL INTERN PROGRAM

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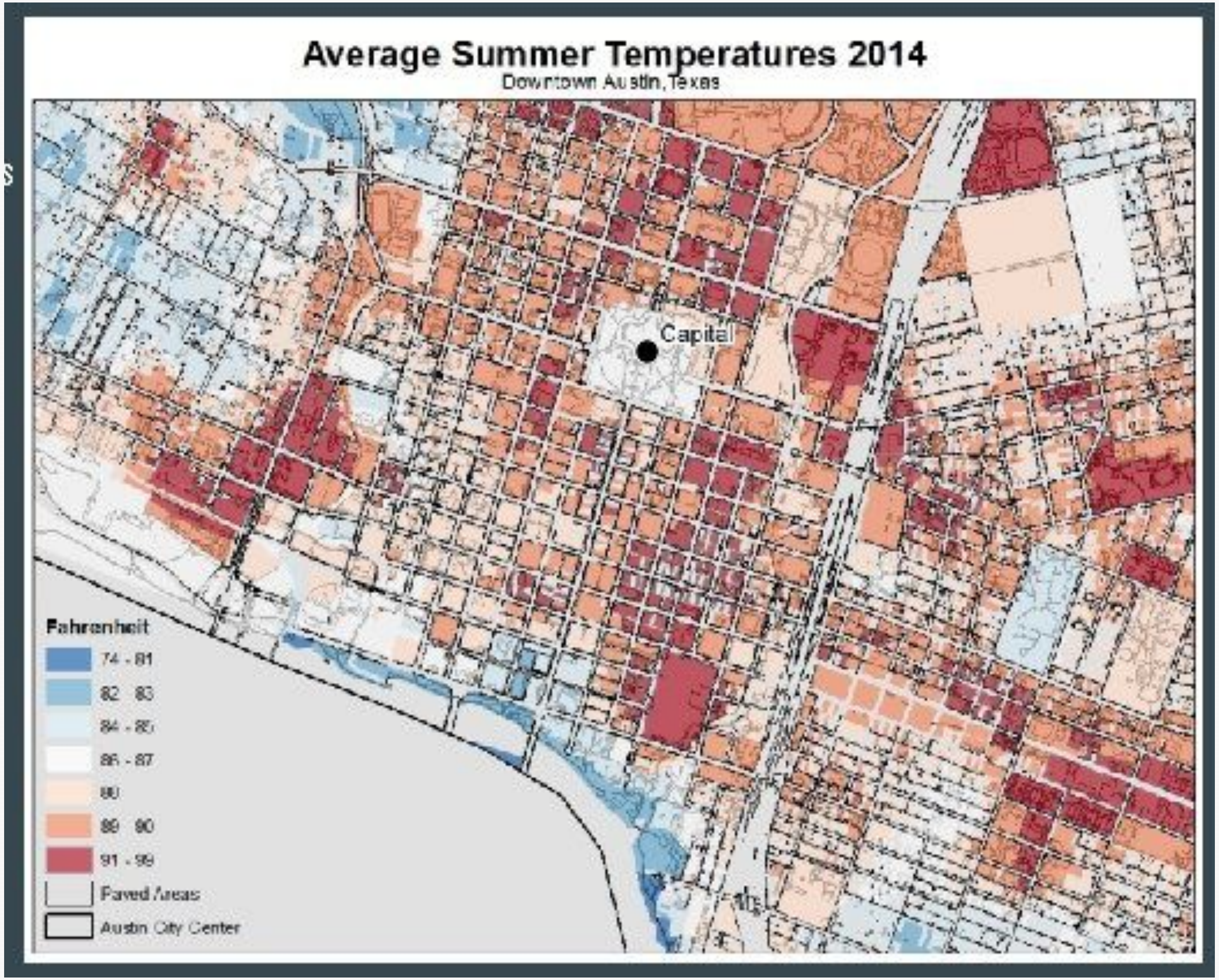
Research Question

How can developed land cover and weather trends be used to forecast the Urban Heat Island Effect?

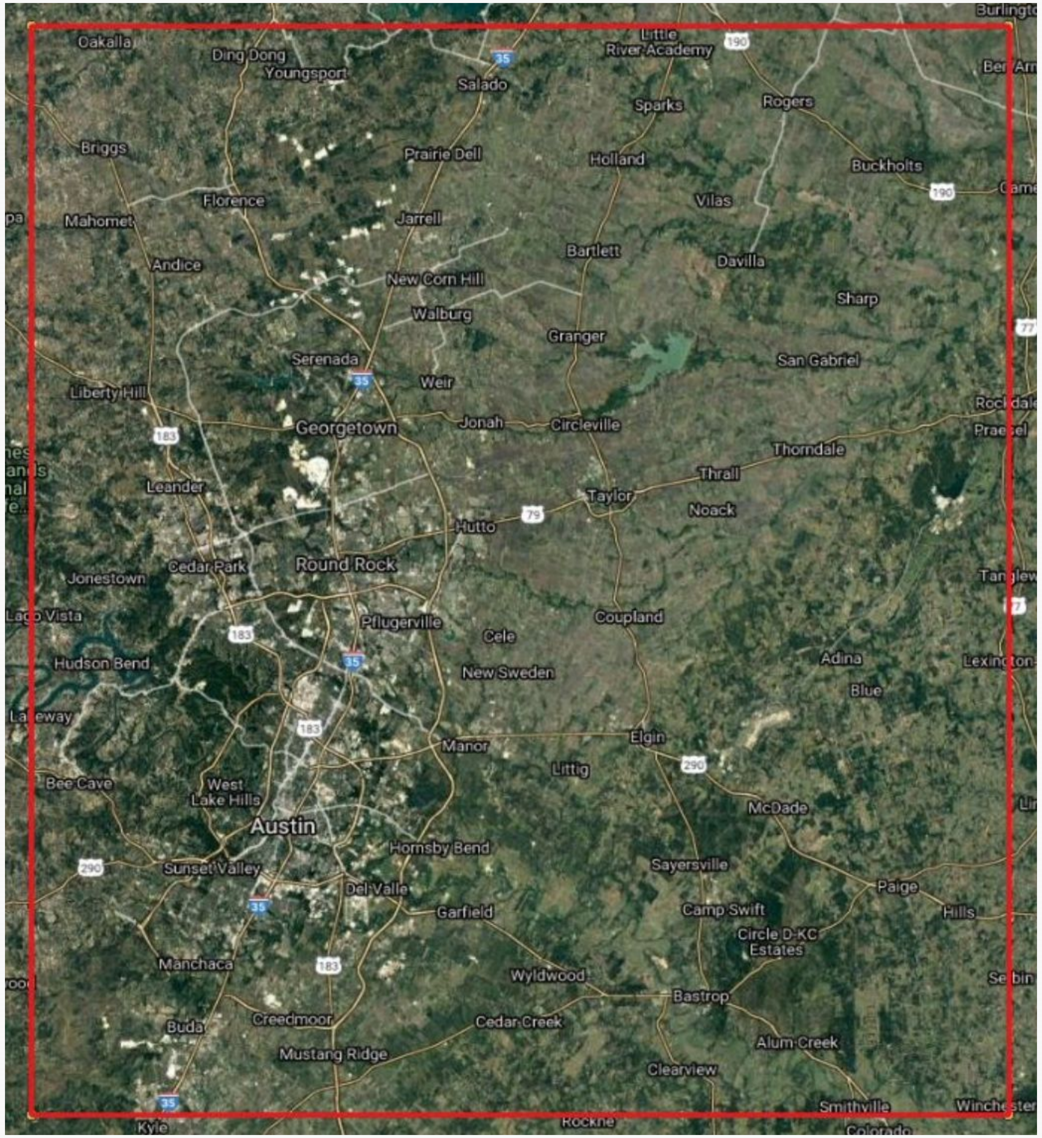
Introduction



Hayhoe et al., 2014

- Urban Heat Islands
- Trend changes with Urban Sprawl
- Hayhoe et al., 2014

Study Site



Greater Austin Region (TX, USA)

Climate

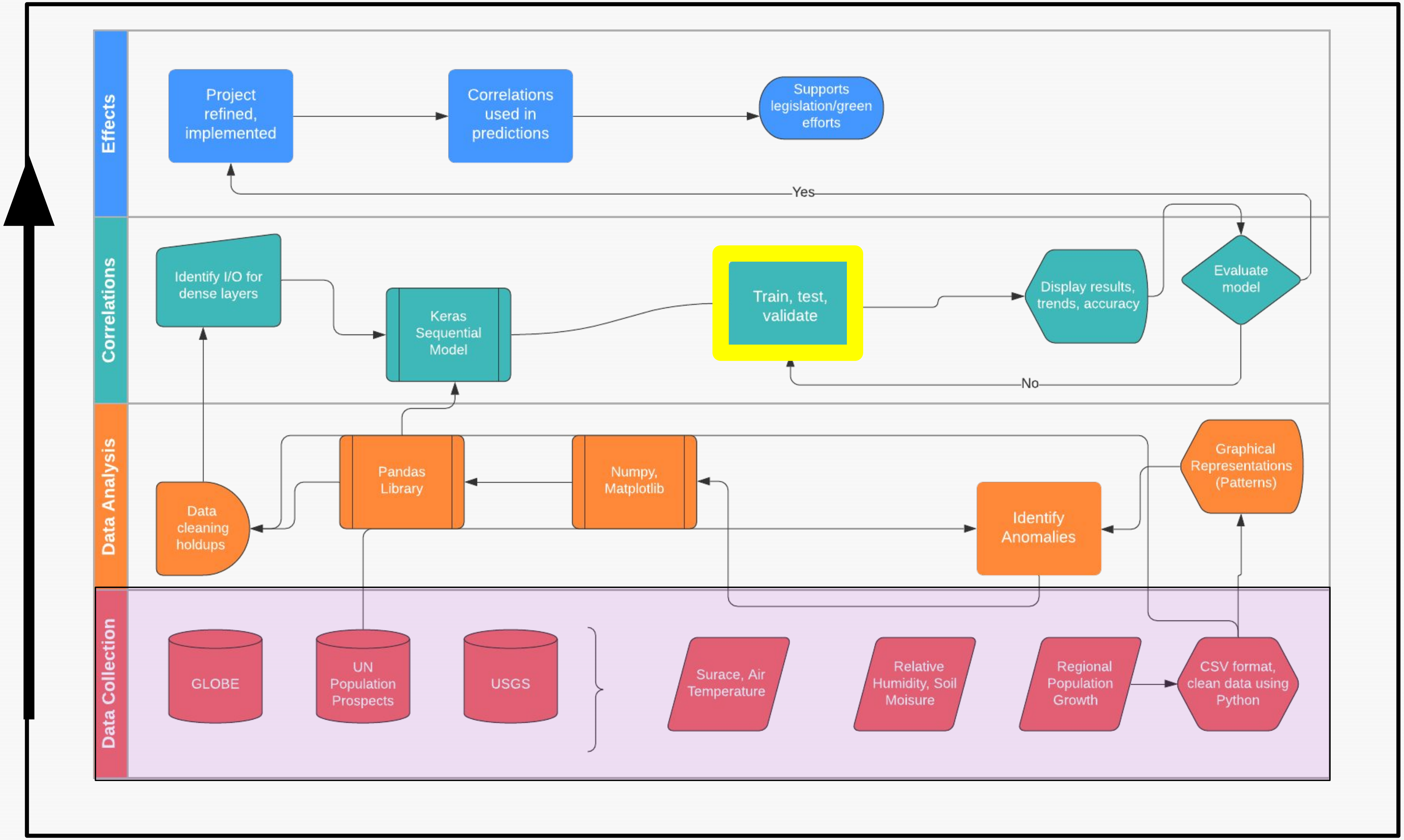
- ❑ Köppen Climate Classification
  - ❑ Humid Subtropical Climate
- ❑ Evenly distributed precipitation
  - ❑ May, October, June Peaks
- ❑ Southerly winds
- ❑ Low stratus clouds at night
- ❑ Hottest year: 2017, coldest: 1899
  - ❑ Progressive Increase

Google Maps

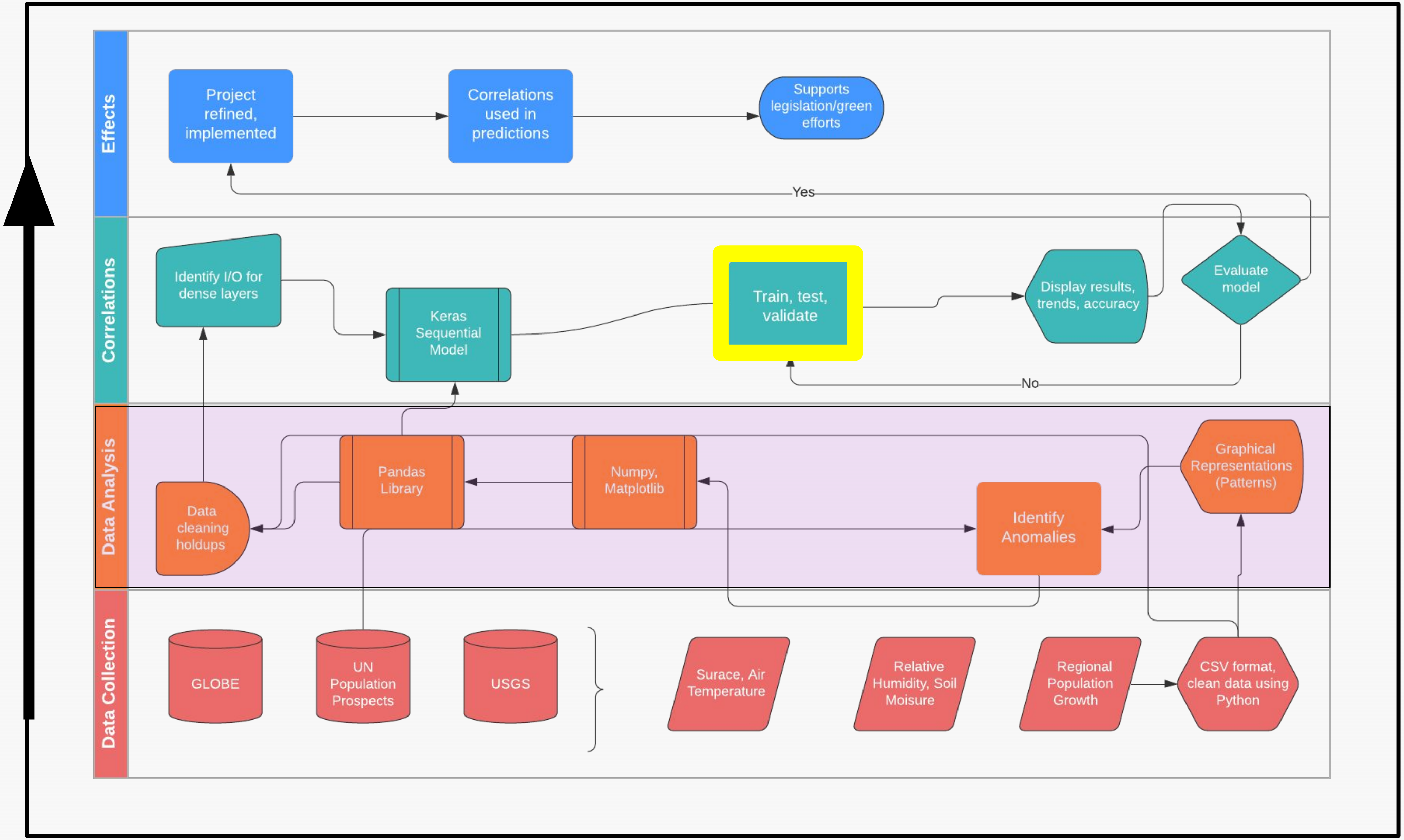
Identifying Correlations Between Environmental Factors

Part 1: Computational Modeling

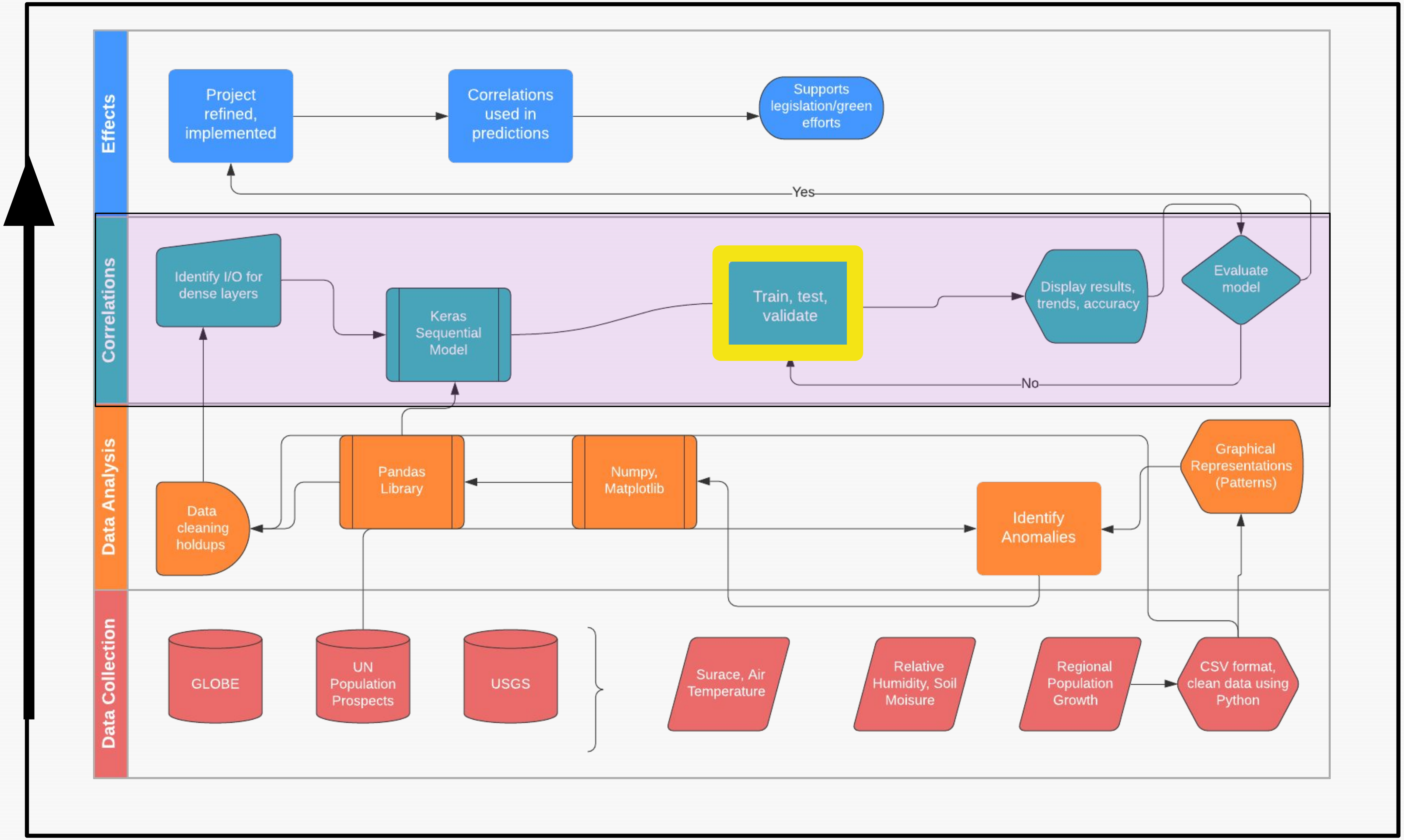
Research Methods: Planning



Research Methods: Planning



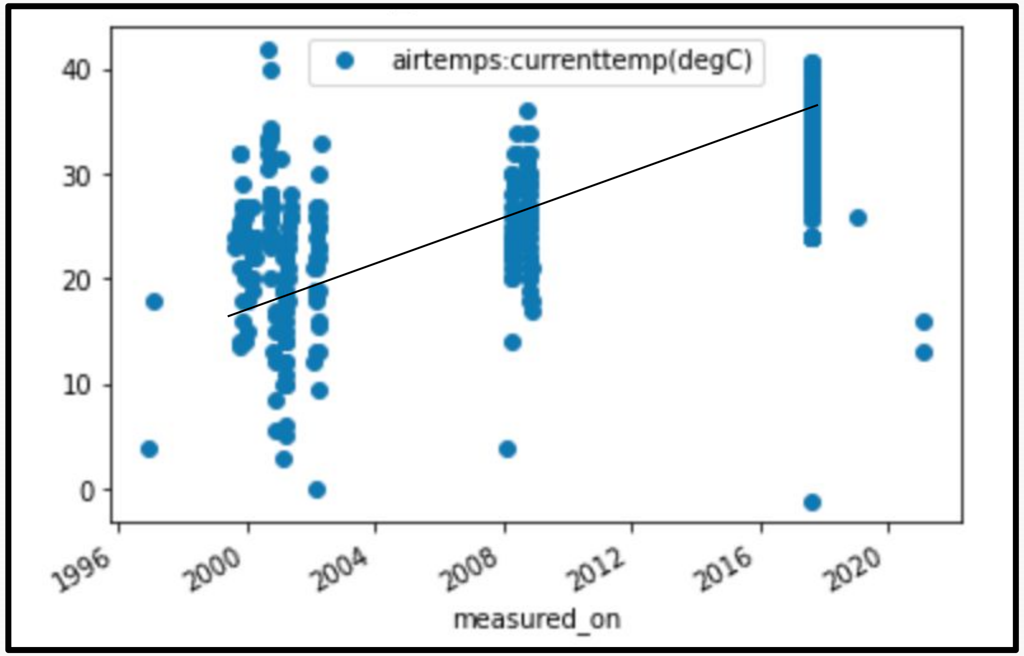
Research Methods: Planning



Results

Correlations, precision & recall

```
Real Output <==> Predictions (First 10 values)
[10.2] <==> [10.19517]
[10.2] <==> [10.24102]
[9.4] <==> [10.206987]
[10.4] <==> [11.291314]
[10.4] <==> [11.104922]
[9.8] <==> [10.973987]
[13.7] <==> [11.557368]
[13.8] <==> [10.897681]
[11.9] <==> [11.373532]
[11.9] <==> [12.201732]
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense (Dense)                (None, 32)                96
_________________________________________________________________
dense_1 (Dense)              (None, 10)                330
_________________________________________________________________
dense_2 (Dense)              (None, 1)                 11
=================================================================
Total params: 437
Trainable params: 437
Non-trainable params: 0
```



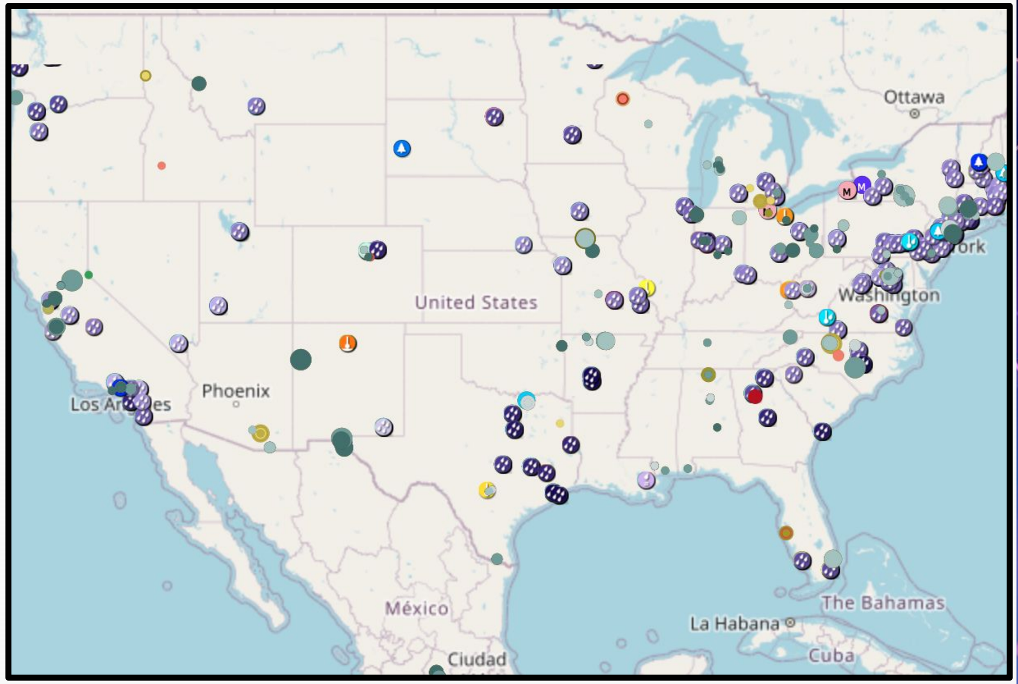
Upward trend in median air temperature in study site

Research Methods: Data

```
atemp.info()

<class 'pandas.core.frame.DataFrame'>
Int64Index: 571 entries, 1 to 571
Data columns (total 14 columns):
 #   Column                       Non-Null Count  Dtype
---  ------                       --------------  -----
 0   organization_id              571 non-null    object
 1   org_name                     571 non-null    object
 2   site_id                      571 non-null    object
 3   site_name                    571 non-null    object
 4   latitude                     571 non-null    object
 5   longitude                    571 non-null    object
 6   elevation                    571 non-null    object
 7   measured_on                  571 non-null    datetime64[ns]
 8   airtemps:userid              571 non-null    float64
 9   airtemps:measuredat          571 non-null    object
 10  airtemps:solarmeasuredat     571 non-null    object
 11  airtemps:currenttemp(degC)   571 non-null    float64
 12  airtemps:comments            342 non-null    object
 13  airtemps:globeteams          0 non-null      float64
dtypes: datetime64[ns](1), float64(3), object(10)
memory usage: 66.9+ KB
```

Pandas Dataframe Summary



GLOBE Visualization System

Discussion

Importing Keras and Modelling

```
from oauth2client.client import GoogleCredentials

# Keras requirements
from tensorflow import keras
from tensorflow.keras import layers
from tensorflow.keras.models import Sequential, load_model
from tensorflow.keras.callbacks import EarlyStopping

from google.colab import drive
```

```
Requirement already satisfied: gast==0.2.2 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (0.2.2)
Requirement already satisfied: grpcio>=1.8.6 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (1.15.0)
Requirement already satisfied: numpy<2.0,>=1.16.0 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (1.16.4)
Requirement already satisfied: protobuf>=3.8.0 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (3.8.0)
Requirement already satisfied: scipy==1.2.2; python_version < "3" in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (1.2.2)
Requirement already satisfied: six>=1.12.0 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (1.15.0)
Requirement already satisfied: wheel; python_version < "3" in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (0.36.2)
Requirement already satisfied: wrapt>=1.11.1 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (1.11.2)
Requirement already satisfied: keras-preprocessing>=1.1.0 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (1.1.0)
Requirement already satisfied: backports.weakref>=1.0rc1; python_version < "3.4" in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (1.0.post1)
Requirement already satisfied: tensorflow-estimator<2.2.0,>=2.1.0rc0 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (2.1.0)
Requirement already satisfied: keras-applications>=1.0.8 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (1.0.8)
Requirement already satisfied: functools32>=3.2.3; python_version < "3" in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (3.2.3.post2)
Requirement already satisfied: termcolor>=1.1.0 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (1.1.0)
Requirement already satisfied: absl-py>=0.7.0 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (0.7.1)
Requirement already satisfied: opt-einsum>=2.3.2 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (2.3.2)
Requirement already satisfied: tensorboard<2.2.0,>=2.1.0 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (2.1.0)
Requirement already satisfied: google-pasta>=0.1.6 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (0.1.7)
Requirement already satisfied: enum34>=1.1.6; python_version < "3.4" in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (1.1.6)
Requirement already satisfied: mock>=2.0.0; python_version < "3" in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (2.0.0)
Requirement already satisfied: astor>=0.6.0 in /usr/local/lib/python2.7/dist-packages (from tensorflow-gpu) (0.8.1)
Requirement already satisfied: futures>=2.2.0 in /usr/local/lib/python2.7/dist-packages (from grpcio>=1.8.6->tensorflow-gpu) (3.2.0)
Requirement already satisfied: setuptools in /usr/local/lib/python2.7/dist-packages (from protobuf>=3.8.0->tensorflow-gpu) (44.1.1)
Requirement already satisfied: h5py in /usr/local/lib/python2.7/dist-packages (from keras-applications>=1.0.8->tensorflow-gpu) (2.8.0)
Requirement already satisfied: google-auth-oauthlib<0.5,>=0.4.1 in /usr/local/lib/python2.7/dist-packages (from tensorboard<2.2.0,>=2.1.0->tensorflow-gpu) (0.4
Requirement already satisfied: werkzeug>=0.11.15 in /usr/local/lib/python2.7/dist-packages (from tensorboard<2.2.0,>=2.1.0->tensorflow-gpu) (0.15.5)
Requirement already satisfied: google-auth<2,>=1.6.3 in /usr/local/lib/python2.7/dist-packages (from tensorboard<2.2.0,>=2.1.0->tensorflow-gpu) (1.33.1)
Requirement already satisfied: requests<3,>=2.21.0 in /usr/local/lib/python2.7/dist-packages (from tensorboard<2.2.0,>=2.1.0->tensorflow-gpu) (2.23.0)
Requirement already satisfied: markdown>=2.6.8 in /usr/local/lib/python2.7/dist-packages (from tensorboard<2.2.0,>=2.1.0->tensorflow-gpu) (3.1.1)
Requirement already satisfied: funcsigs>=1; python_version < "3.3" in /usr/local/lib/python2.7/dist-packages (from mock>=2.0.0; python_version < "3"->tensorflo
Requirement already satisfied: pbr>=0.11 in /usr/local/lib/python2.7/dist-packages (from mock>=2.0.0; python_version < "3"->tensorflow-gpu) (5.4.0)
Requirement already satisfied: requests-oauthlib>=0.7.0 in /usr/local/lib/python2.7/dist-packages (from google-auth-oauthlib<0.5,>=0.4.1->tensorboard<2.2.0,>=2
Requirement already satisfied: cachetools<5.0,>=2.0.0 in /usr/local/lib/python2.7/dist-packages (from google-auth<2,>=1.6.3->tensorboard<2.2.0,>=2.1.0->tensorf
Requirement already satisfied: pyasn1-modules>=0.2.1 in /usr/local/lib/python2.7/dist-packages (from google-auth<2,>=1.6.3->tensorboard<2.2.0,>=2.1.0->tensorfl
Requirement already satisfied: rsa<4.6; python_version < "3.6" in /usr/local/lib/python2.7/dist-packages (from google-auth<2,>=1.6.3->tensorboard<2.2.0,>=2.1.0
Requirement already satisfied: urllib3!=1.25.0,!=1.25.1,<1.26,>=1.21.1 in /usr/local/lib/python2.7/dist-packages (from requests<3,>=2.21.0->tensorboard<2.2.0,>
Requirement already satisfied: chardet<4,>=3.0.2 in /usr/local/lib/python2.7/dist-packages (from requests<3,>=2.21.0->tensorboard<2.2.0,>=2.1.0->tensorflow-gpu
Requirement already satisfied: certifi>=2017.4.17 in /usr/local/lib/python2.7/dist-packages (from requests<3,>=2.21.0->tensorboard<2.2.0,>=2.1.0->tensorflow-gp
Requirement already satisfied: idna<3,>=2.5 in /usr/local/lib/python2.7/dist-packages (from requests<3,>=2.21.0->tensorboard<2.2.0,>=2.1.0->tensorflow-gpu) (2.
Requirement already satisfied: oauthlib>=3.0.0 in /usr/local/lib/python2.7/dist-packages (from requests-oauthlib>=0.7.0->google-auth-oauthlib<0.5,>=0.4.1->tens
Requirement already satisfied: pyasn1<0.5.0,>=0.4.1 in /usr/local/lib/python2.7/dist-packages (from pyasn1-modules>=0.2.1->google-auth<2,>=1.6.3->tensorboard<2
Reading package lists... Done
Building dependency tree
Reading state information... Done
graphviz is already the newest version (2.40.1-2).
0 upgraded, 0 newly installed, 0 to remove and 40 not upgraded.
```

```
Real Output <==> Predictions
[10.2] <==> [10.19517]
[10.2] <==> [10.24102]
[9.4] <==> [10.206987]
[10.4] <==> [11.291314]
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[9.8] <==> [10.973987]
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[13.8] <==> [10.897681]
[11.9] <==> [11.373532]
[11.9] <==> [12.201732]
Model: "sequential"
```
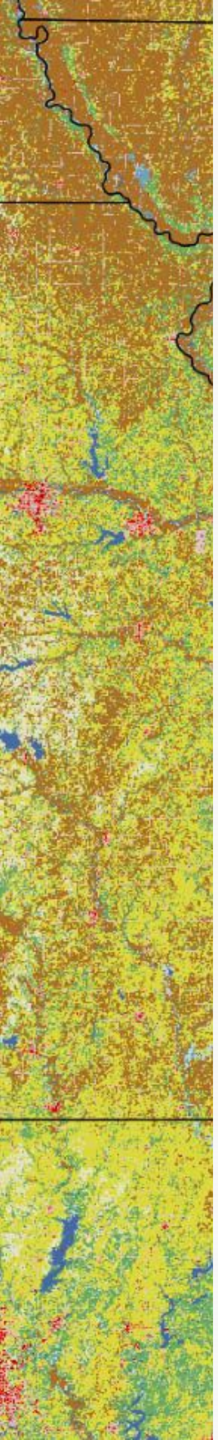
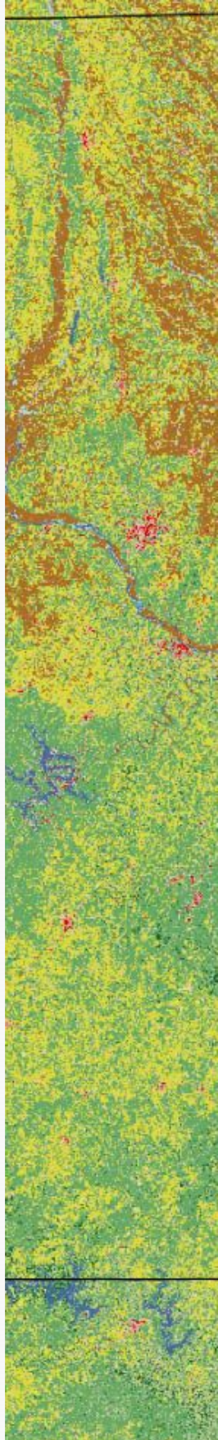
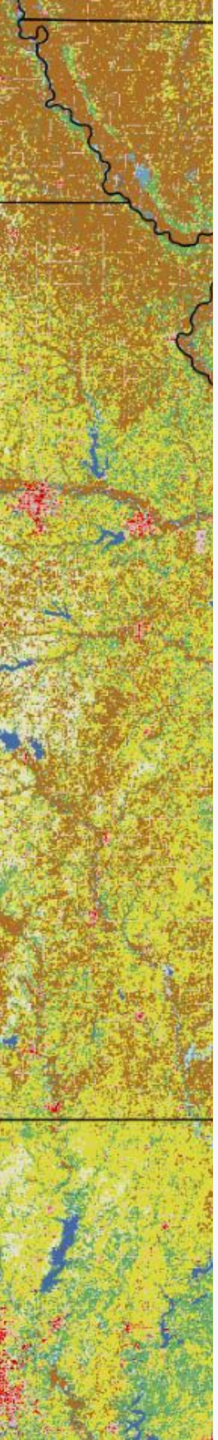

Model's validation losses (discrepancy between verified data and predicted output) < 4%



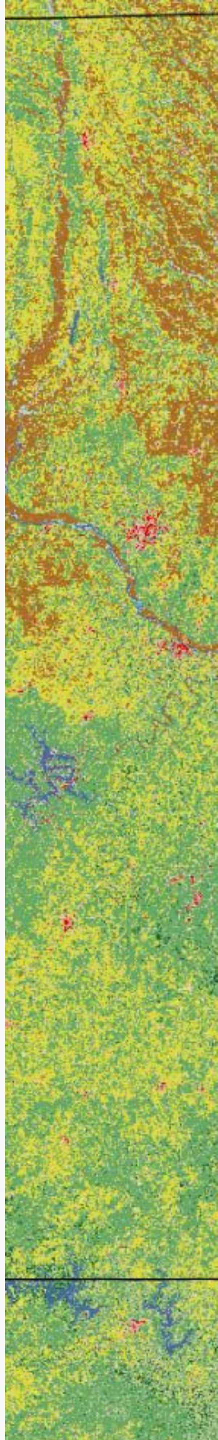
Predicting Future Land Use/Land Cover

Part 2: Satellite Imagery

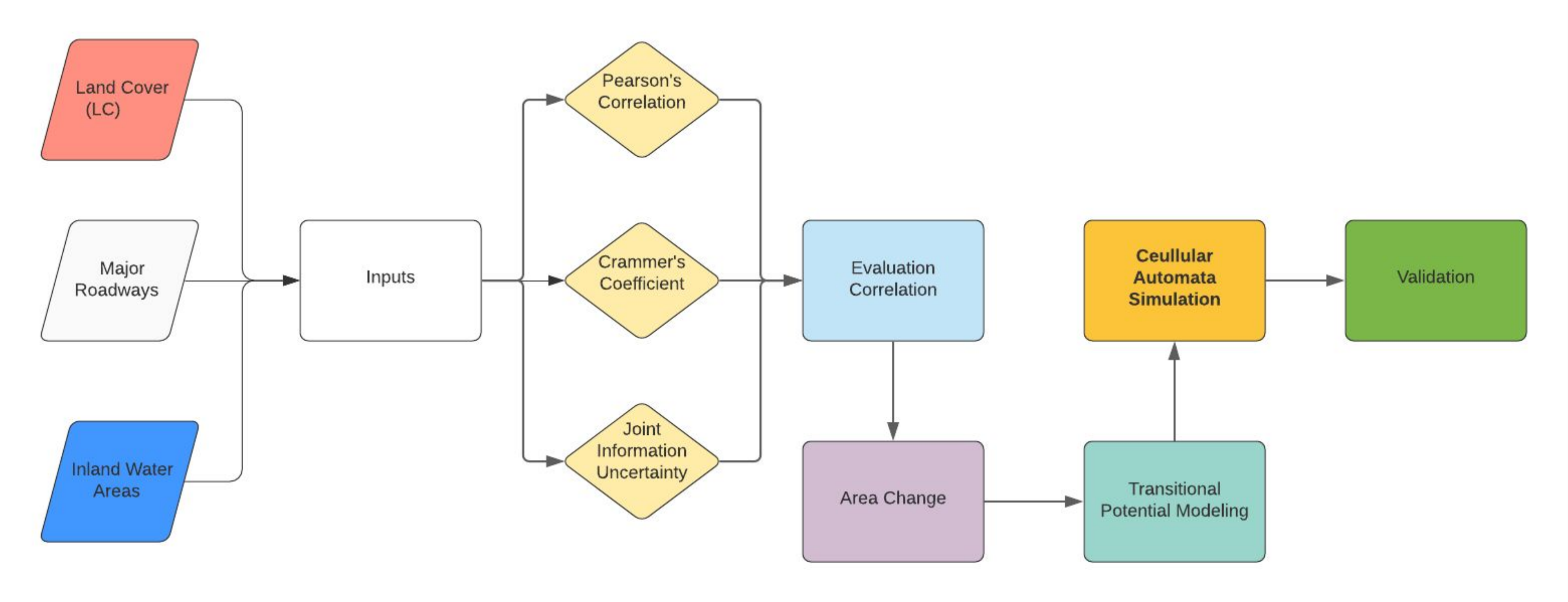




Modules for Land Use Change Simulations (MOLUSCE)

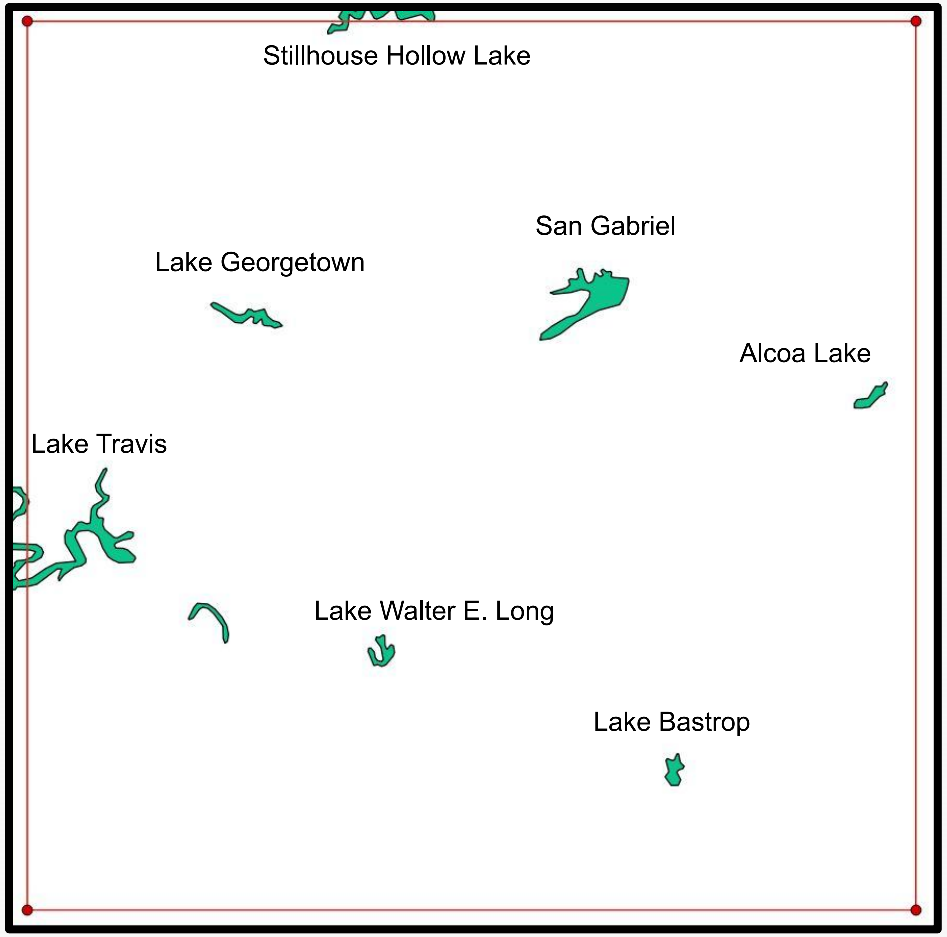


Prediction Model Process

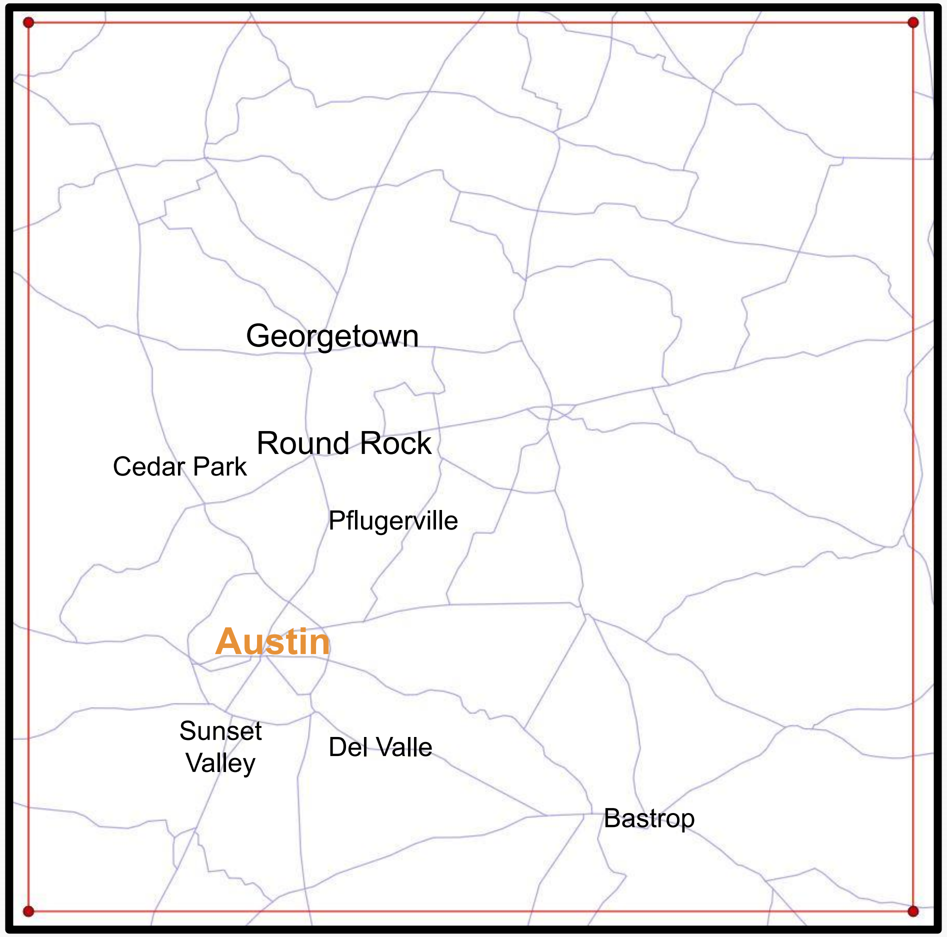


wiki.gis-lab.info

Inputs



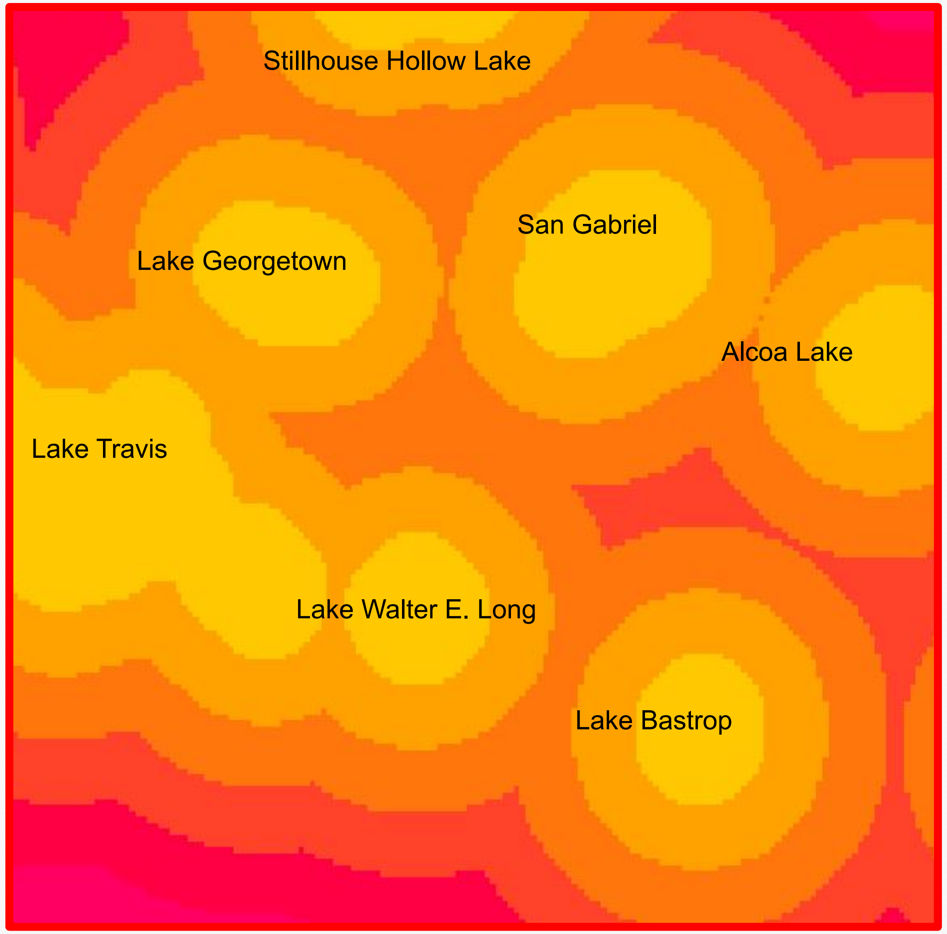
Inland Water Input



Major Roadways

DIVA-GIS

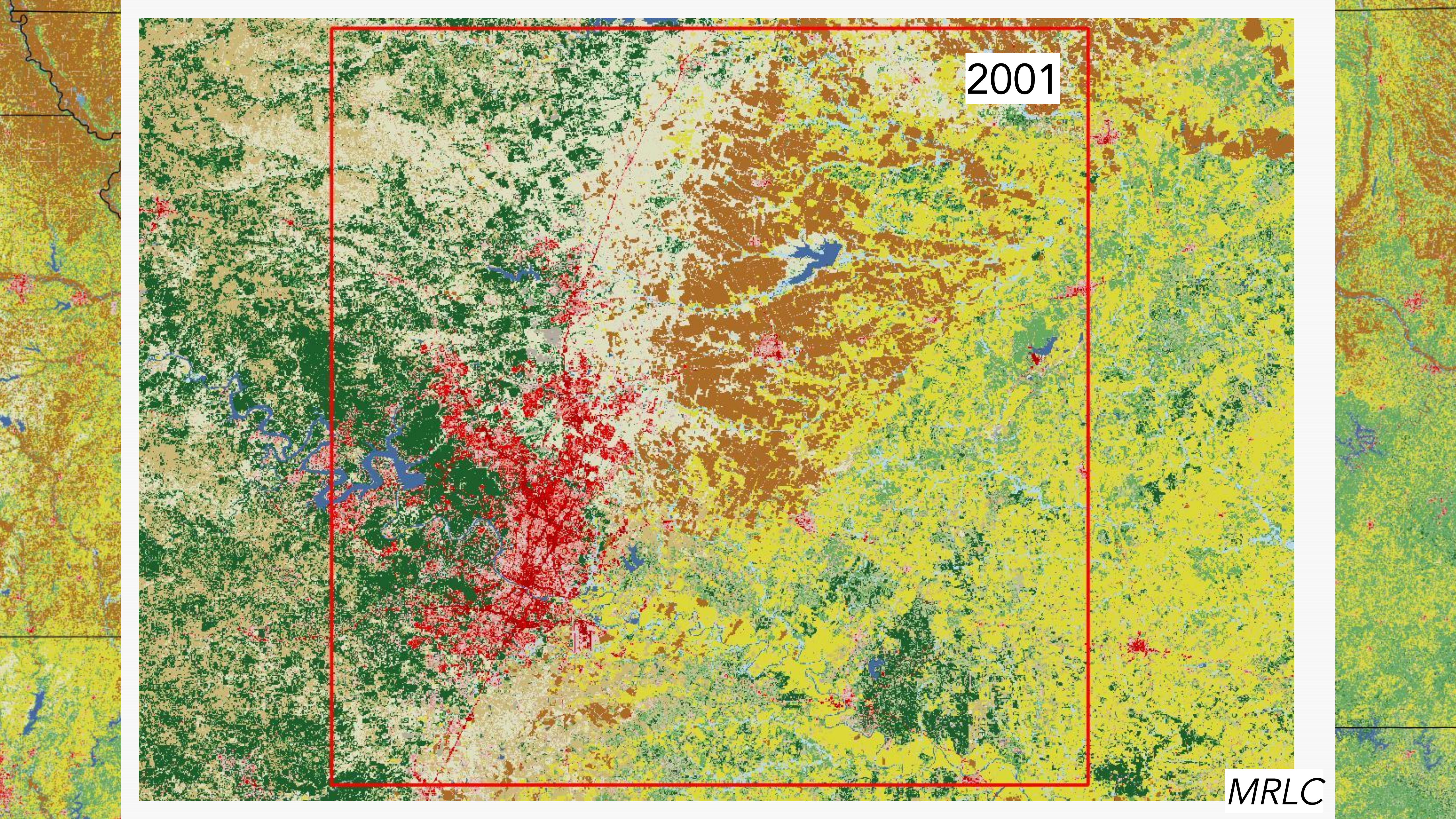
Euclidian Distance From

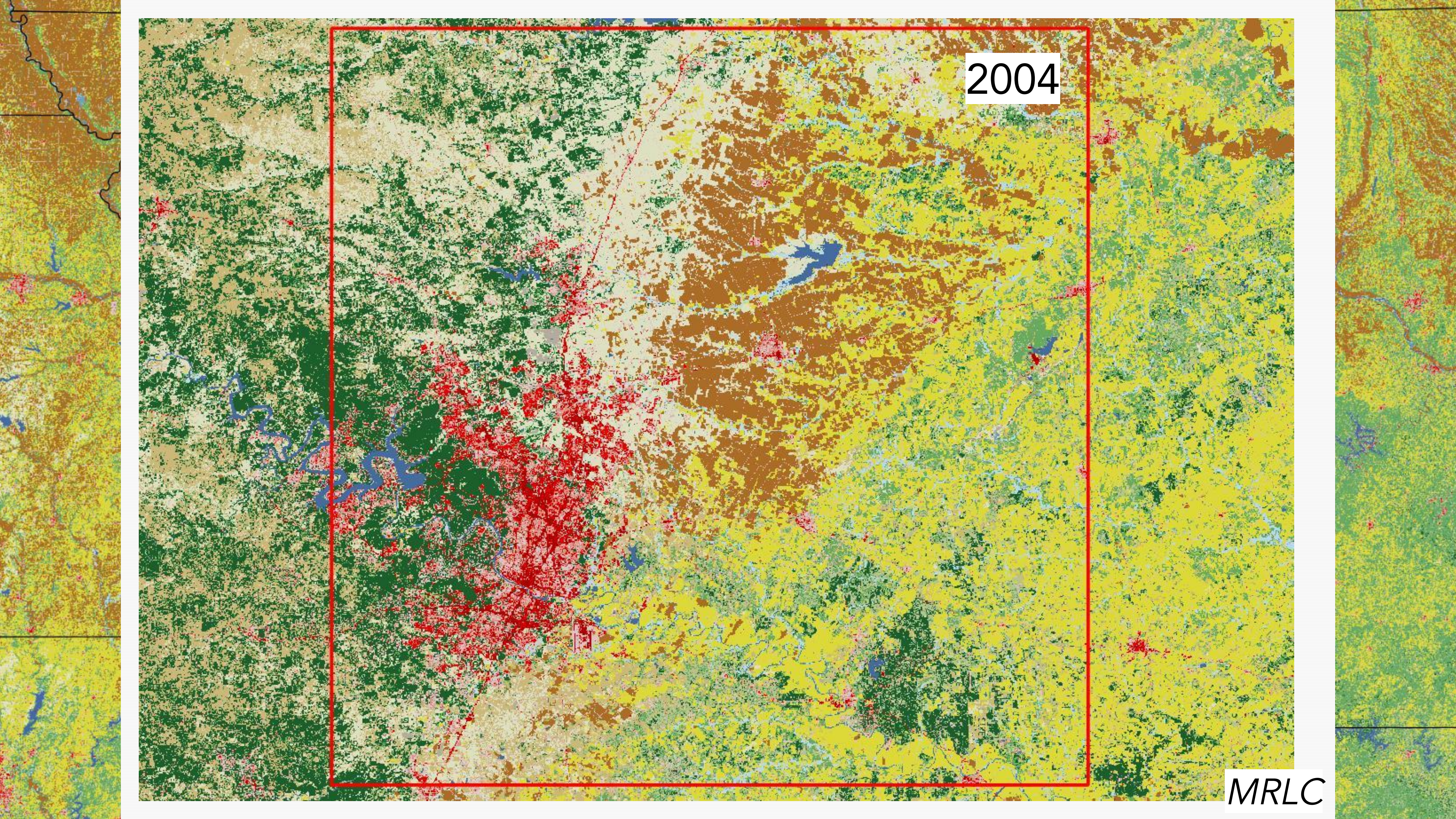


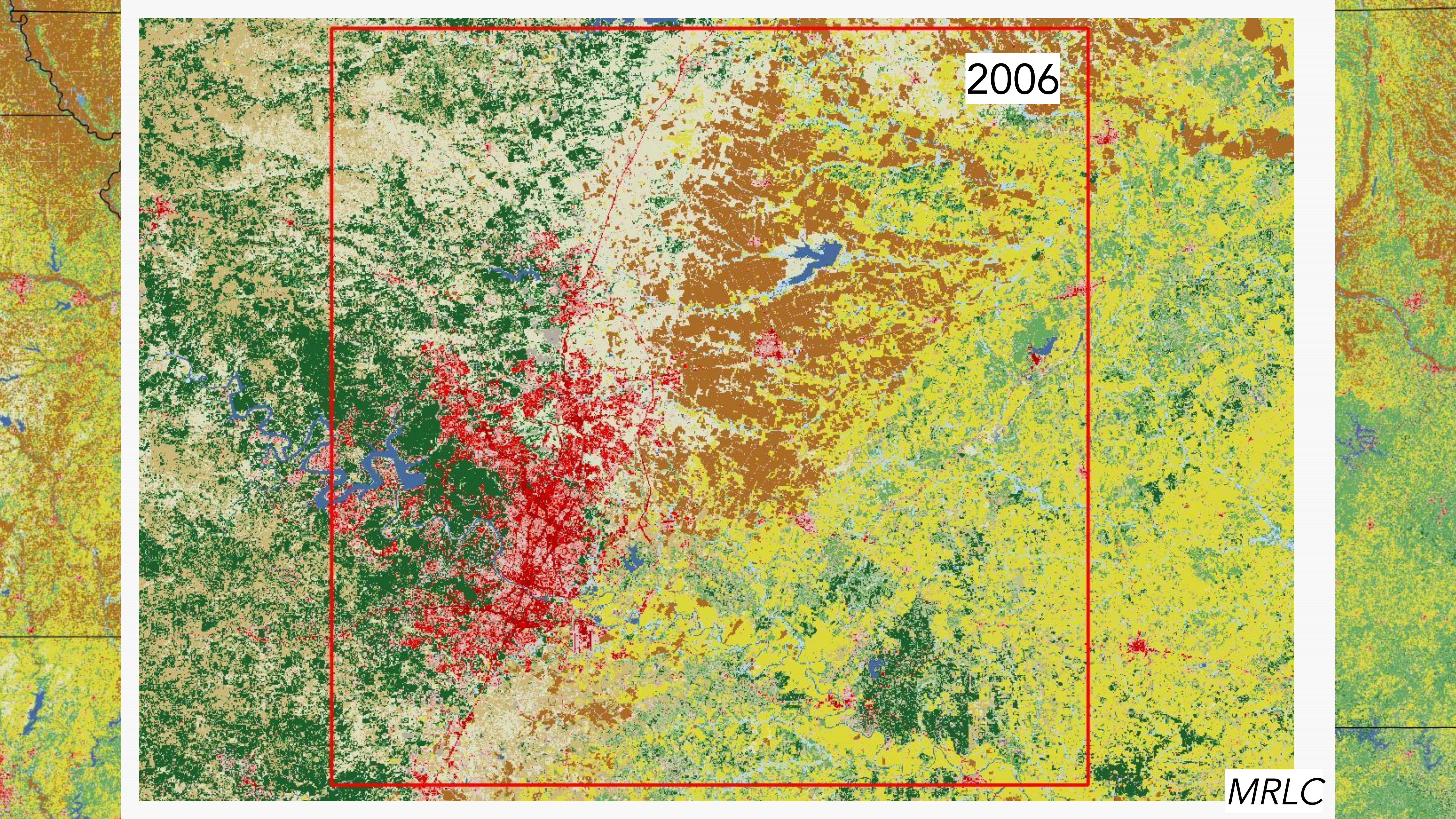
Distance From Water

Distance From Road

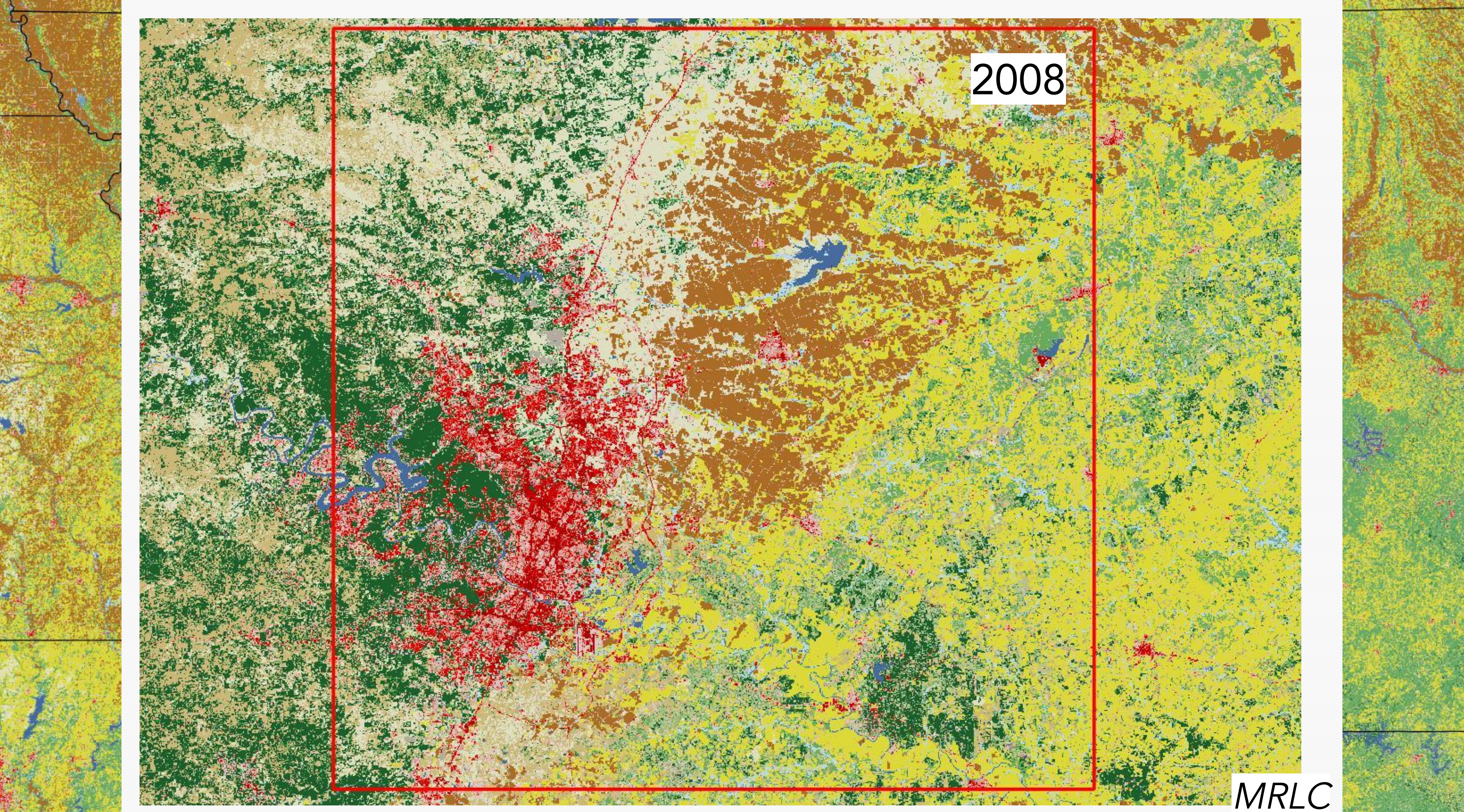
ArcMap 10.8


2001
MRLC

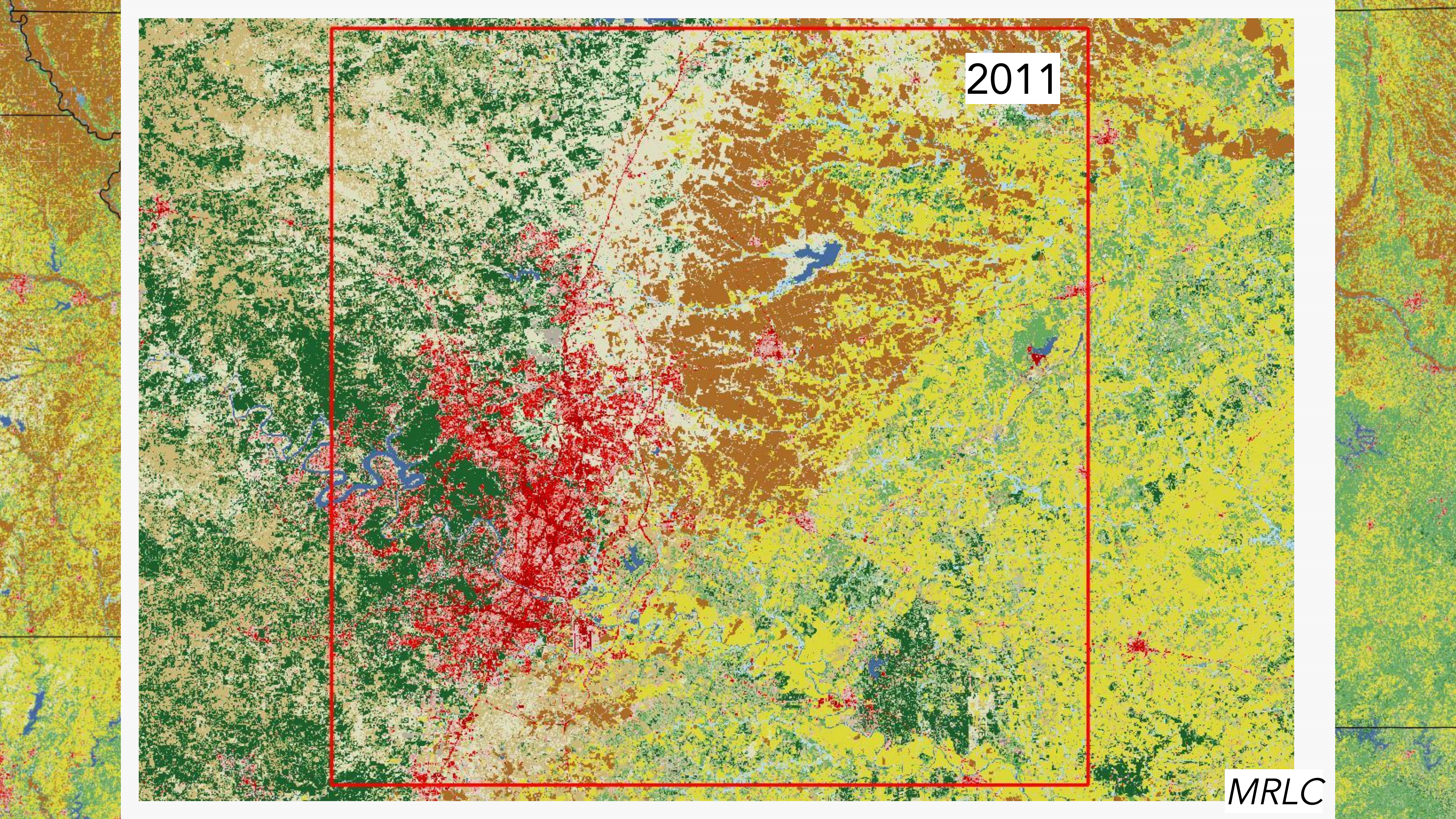

2004
MRLC



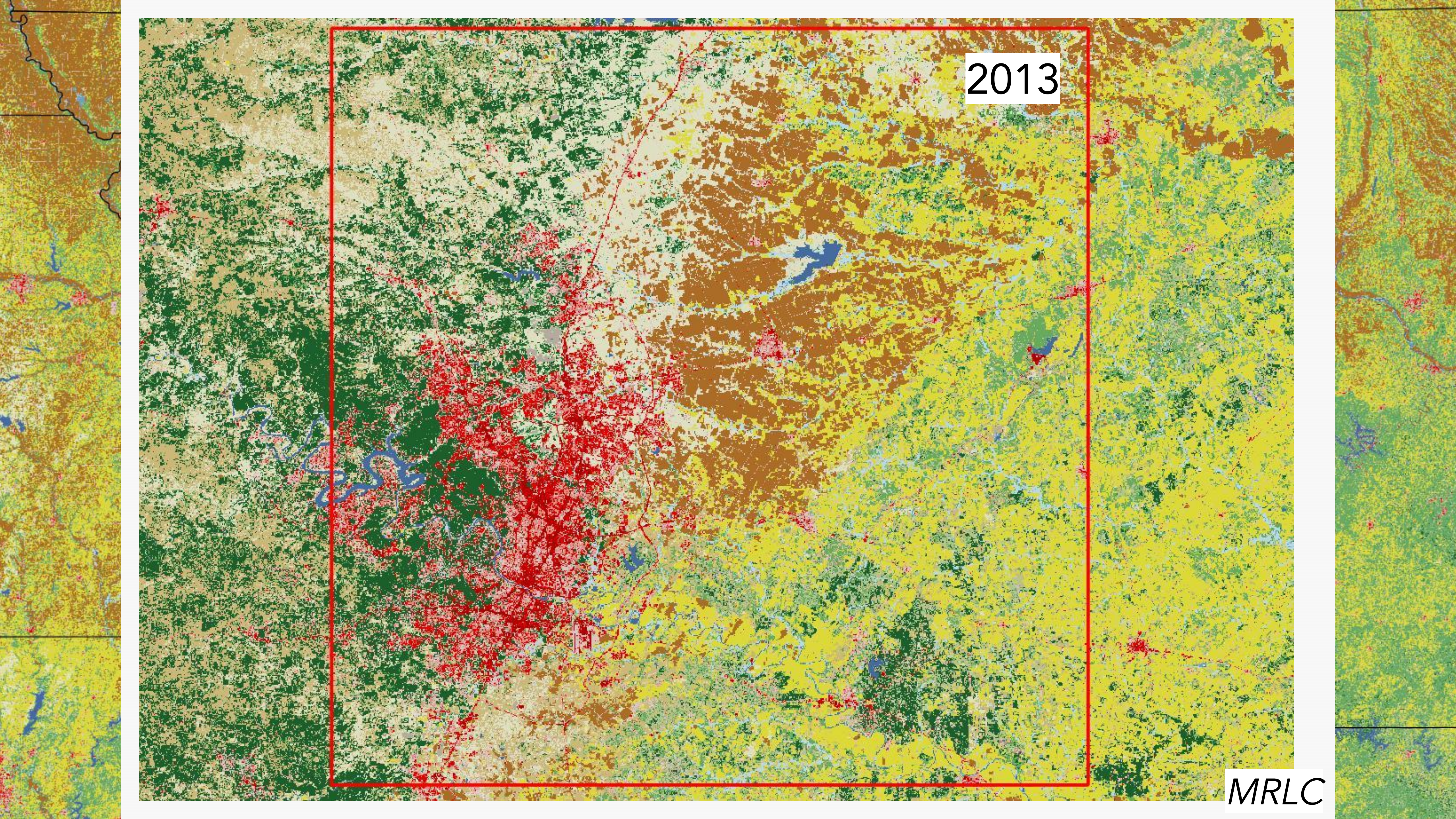
MRLC

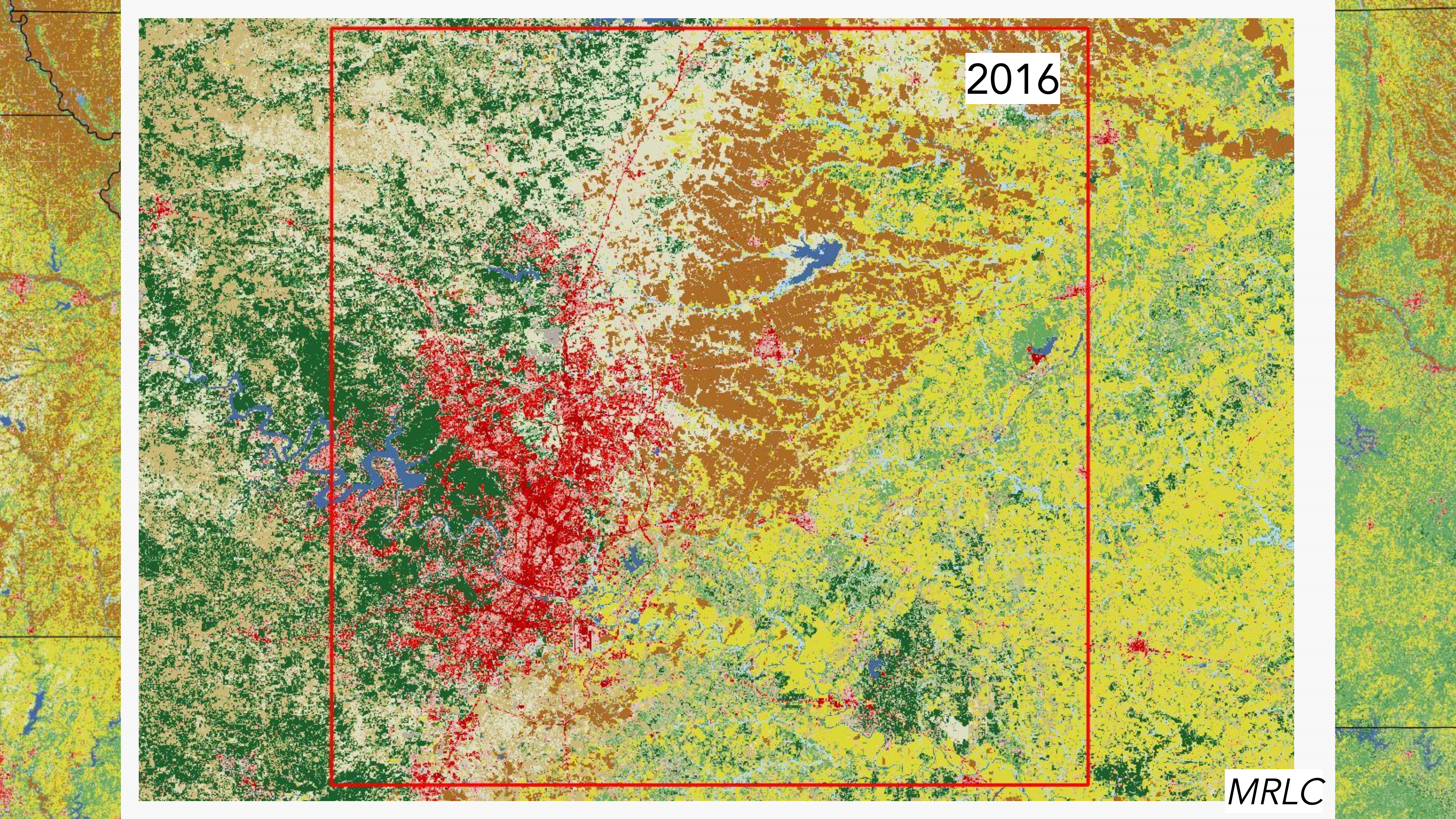


MRLC

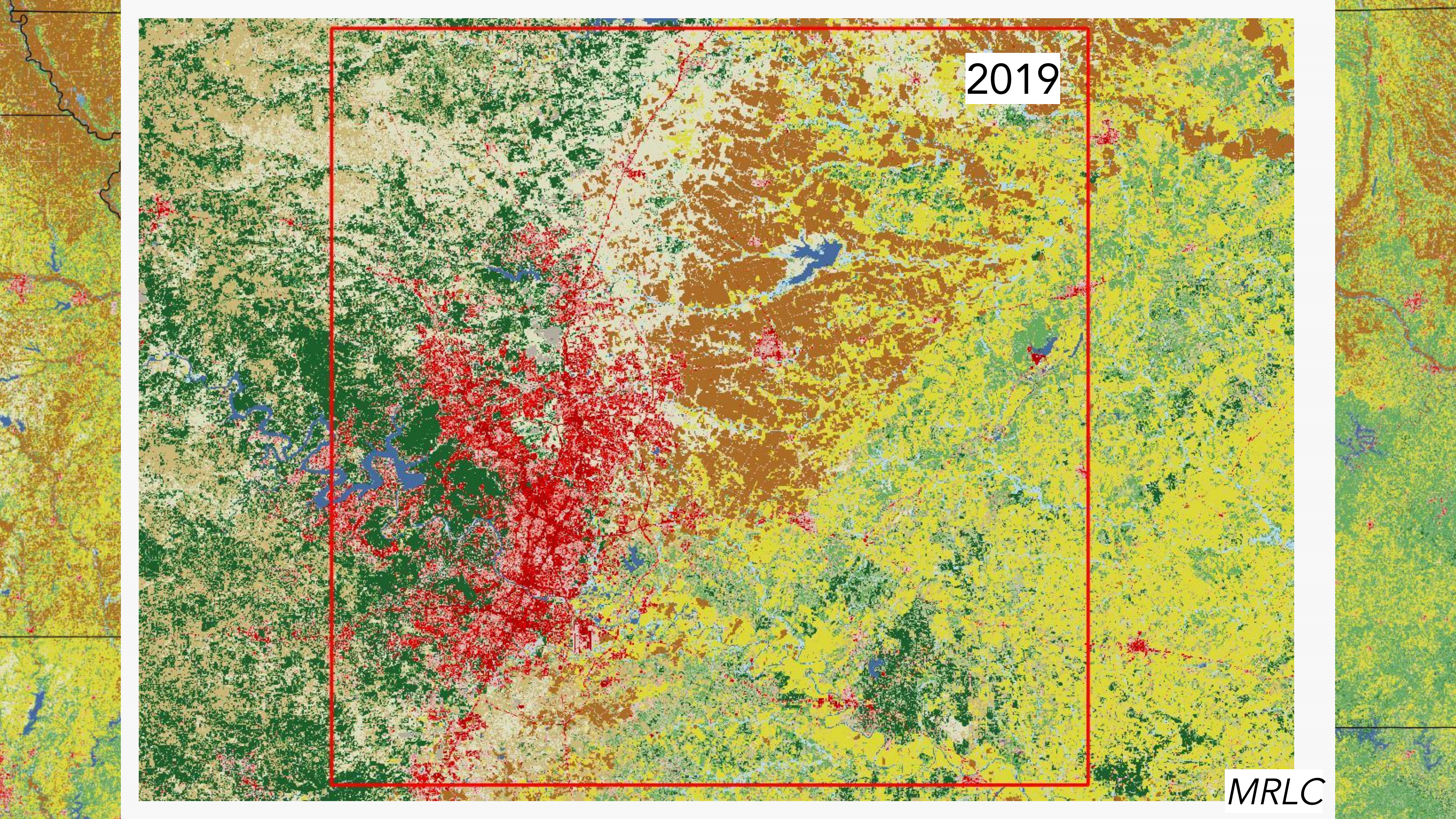


MRLC

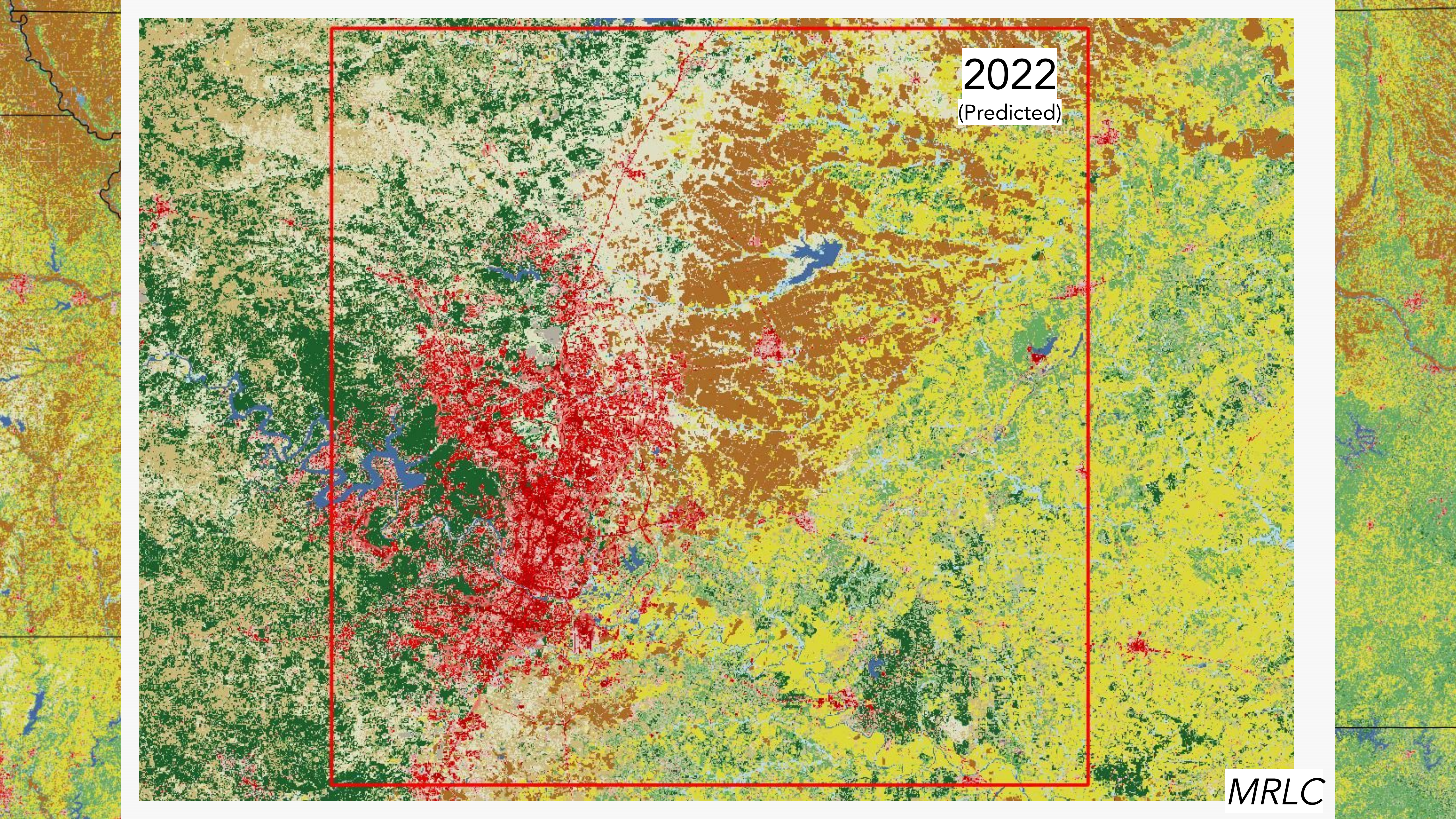

2013
MRLC



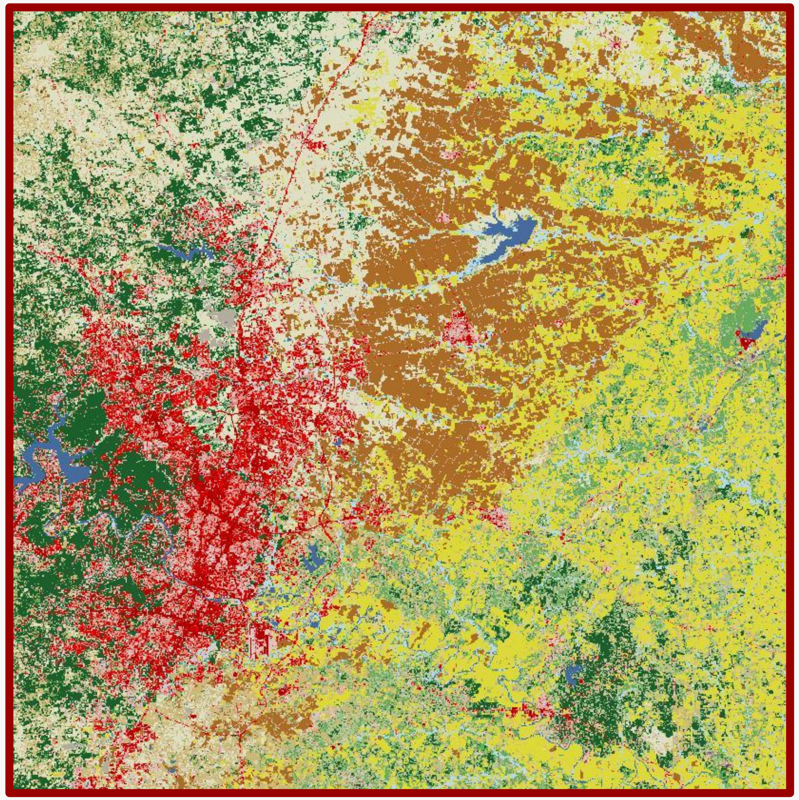
MRLC

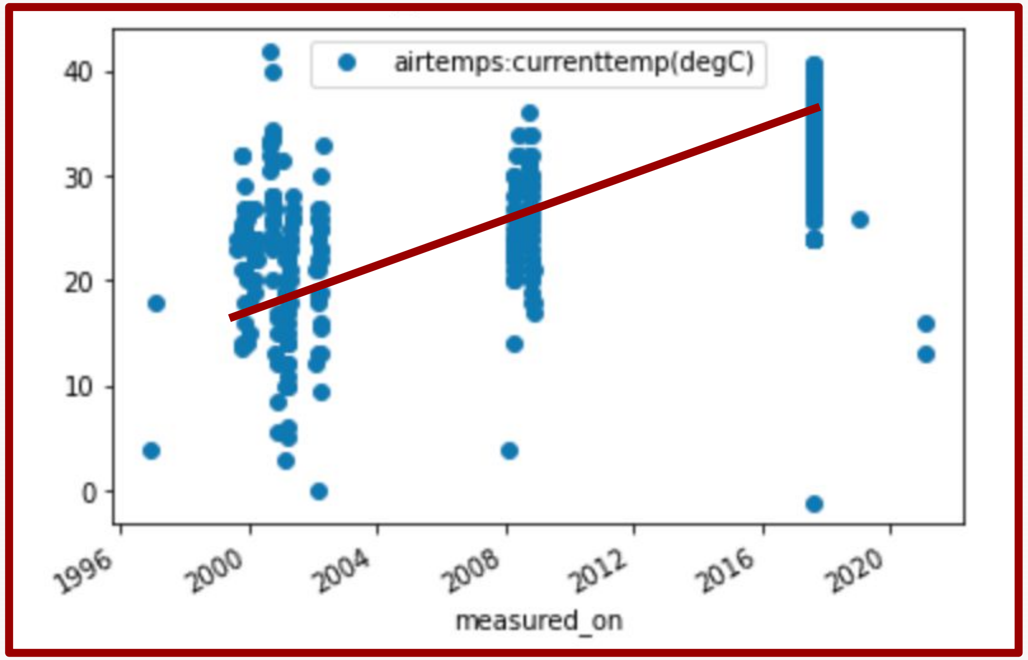


MRLC


2022
(Predicted)
MRLC

Combining Parts





Potential Use

Green Efforts

References

- Guidigan, M. L. G., Sanou, C. L., Ragatoa, D. S., Fafa, C. O., & Mishra, V. N. (2019). Assessing land use/land cover dynamic and its impact in Benin Republic using land change model and CCI-LC products. *Earth Systems and Environment*, *3*(1), 127-137.
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- Rangarajan, S. (2021). Predicting the Future Land Use and Land Cover Changes for Bhavani Basin, Tamil Nadu, India Using QGIS MOLUSCE Plugin.